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SAWD II PREPROTOTYPE SOLID AMINE, CO_2 REMOVAL SUBSYSTEM

FINAL REPORT

PREPARED UNDER CONTRACT NAS 9-16978

BY

UNITED TECHNOLOGIES CORPORATION

HAMILTON STANDARD DIVISION

SPACE AND SEA SYSTEMS

WINDSOR LOCKS, CONNECTICUT

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LYNDON B. JOHNSON SPACE CENTER

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PREPARED BY: G. F. Allen 11/15/90
G. F. ALLEN
SENIOR ENGINEER

APPROVED BY: A. K. Colling 16 Nov. 1990
A. K. COLLING
PROJECT ENGINEERING MANAGER

APPROVAL BY: R J Cusick 12/21/90
R. J. CUSICK
TECHNICAL MANAGER
NASA/JSC

UNITED TECHNOLOGIES
HAMILTON STANDARD

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ABSTRACT

This report presents a final review of the design, development and testing of a preprototype Solid Amine, Carbon Dioxide (CO_2) removal subsystem. The subsystem which is referred to as SAWD II, (acronym for "Solid Amine Water Desorb, Dual Bed") was developed under contract NAS 9-16978, "Regenerable CO_2 and Humidity Control Systems" for the National Aeronautics and Space Administration.

Also included are some life and parameter test results which were obtained from a single (Zero-G) canister breadboard subsystem which is referred to a SAWD I.

FOREWORD

This final report has been prepared by Hamilton Standard Division of United Technologies Corporation for the National Aeronautics and Space Administration's Lyndon B. Johnson Space Center in accordance with the requirements of Contract NAS 9-16978, "Regenerable CO_2 and Humidity Control Systems".

The guidance and advice provided by the NASA Technical Monitor, Mr. Robert J. Cusick of the Lyndon B. Johnson Space Center's Crew Systems Division, is greatly appreciated.

Hamilton Standard personnel responsible for the conduct and completion of this program were Messrs. Arthur K. Colling, Project Engineering Manager; Timothy A. Nalette, and Gordon F. Allen, Analytical Engineers; and Terry M. Grayson and Michael Emery, Electrical Engineers.

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1.0 SUMMARY

A regenerable, preprototype, subsystem to remove CO_2 from the atmosphere, concentrate the CO_2 and deliver it at pressure was developed based on the following operating conditions and performance requirements.

Crew size - 3-man with nominal CO_2 production of 6.6 lb/day

Cabin CO_2 partial pressure	- 3.0 mm Hg		
CO_2 removal/delivery rate	- 0.275 lb/hr		
CO_2 delivery pressure	- 18.3 ± 0.2 psia		
Cabin temperature	- 65°F to 80°F		
Cabin relative humidity	- 35% to 70%		
Cabin pressure	- 14.7 psia		
Non-testing periods	- Relative Humidity	=	30% to 80
	Temperature	=	50°F to 100°F
	Pressure	=	14.7 psia

Based upon the results of a system analysis, a two-canister configuration that incorporates an accumulator for CO_2 storage/delivery was proposed for the design. Regeneration (desorption) occurs at a steam pressure up to 30 psia. This accomplishes the CO_2 pressurization (for storage and delivery) with the steam generator instead of a compressor. The preliminary subsystem specification is presented in Table 1.0-1.

TABLE 1.0-1

PREPROTOTYPE SAWD SPECIFICATIONS

Number of Canisters	Two (2)
Amine Weight Per Canister	8.1 lb (dry)
Air Flow Rate	14.5 cfm
Absorption Pressure Level	14.7 psia
Absorption Cycle Duration*	
50% Relative Humidity	70 minutes
35% Relative Humidity	45 minutes
70% Relative Humidity	90 minutes
System Pressure Loss	6 in/H_2O
CO_2 Removal/Delivery Rate	0.275 lb/hr
CO_2 Desorption Pressure Level	30 psia
CO_2 Delivery Pressure Level	18.3 psia
System Power Requirement**	454 watts
System Weight	113 lb
System Volume***	7.5 ft^3

*Desorption cycle durations are the same

**For nominal conditions at 50% relative humidity

***Within a 24 X 24 X 31 inch envelope

1.0 SUMMARY (Continued)

To accurately represent the operational characteristic of the CO_2 removal, concentration and delivery functions required in a zero-gravity closed-loop environmental control system, the amine canister, canister isolation valves, and external steam generator were designed to be representative of a flight design. To minimize costs, commercial "off-the-shelf" items were specified to be used to the maximum extent possible. The "as designed" preprototype subsystem is presented schematically on Figure 1.0-1 along with a list of major components.

The subsystem was designed to continuously removes CO_2 from the cabin atmosphere by alternately absorbing and desorbing the amine canisters. Air was to be taken directly from the cabin, passed thru the amine canister where it was stripped of CO_2, humidified with water and then returned to the cabin.

Upon entering the subsystem, the air is directed by one of the three-way valves (item 401 or 403) to the absorbing amine canister. Air passes thru the canister where the CO_2 is removed. During the CO_2 absorption process the heat of absorption is removed from the bed by evaporating water which was added during the previous desorption. This evaporation serves to both maintain a stable water loading in the bed as well as maintain a cool bed temperature. After leaving the absorbing canister the air is directed by the outlet three way valve (item 402 or 404) to the process air blower. The process fan (item 412) provides the necessary head rise to move the air thru the subsystem. After passing thru the fan the air is directed back to the cabin. The absorption is complete when the bed has been dried to the proper moisture level. (70 minutes for 50 percent RH process air).

While one amine bed is absorbing CO_2 the second amine bed is being regenerated (desorbed). Desorption is accomplished by raising the bed temperature. The bed temperature is increased by heating the bed with steam.

At the start of the desorb cycle, the water supply valve (item 409) is opened and water is supplied to the steam generator (item 411) by the water pump

ITEM #	COMPONENT	ITEM #	COMPONENT
101	RELIEF VALVE	308	FLOW TRANSDUCER
102	CHECK VALVE	309	PRESSURE TRANSDUCER
103	BACKPRESSURE REGULATOR	401	CANISTER 1 INLET VALVE
104	PRESSURE REGULATOR	402	CANISTER 1 OUTLET VALVE
105	METERING VALVE	403	CANISTER 2 INLET VALVE
201	AMINE CANISTER #1	404	CANISTER 2 OUTLET VALVE
202	AMINE CANISTER #2	405	ENERGY TRANSFER VALVE
203	ACCUMULATOR	406	DESORPTION DIVERTER VALVE
301	RESISTANCE THERMOMETER	407	CO_2 OVERBOARD VALVE
302	RESISTANCE THERMOMETER	408	CO_2 REDUCTION VALVE
303	RESISTANCE THERMOMETER	409	WATER SUPPLY VALVE
304	RESISTANCE THERMOMETER	410	WATER PUMP
305	RESISTANCE THERMOMETER	411	STEAM GENERATOR
306	RESISTANCE THERMOMETER	412	PROCESS AIR BLOWER
307	PRESSURE SWITCH	500	DRIVER BOX

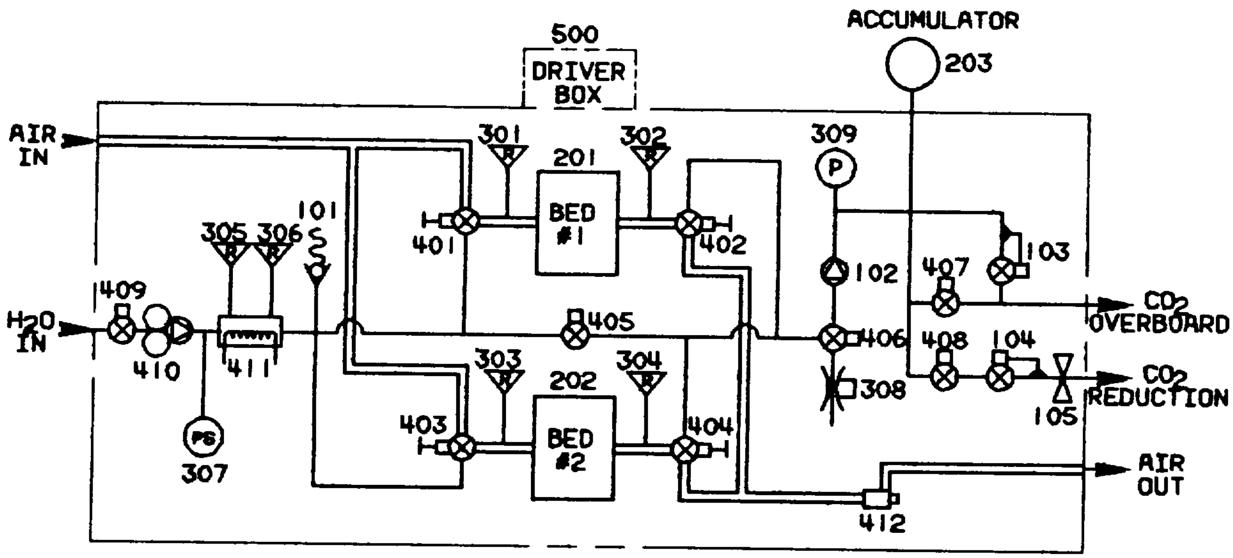

FIGURE 1.0-1
"AS DESIGNED" SAWD II SCHEMATIC DIAGRAM

(item 410). As the liquid water moves thru the steam generator it is first heated to the saturation temperature (between 212 and 250°F depending on the back pressure), then vaporized and finally slightly superheated (280 ± 20°F). The superheated steam is then directed by one of the three way valves (item 401 or 403) to the desorbing amine canister. At the start of the desorb cycle, the residual process air in the amine bed is displaced by the steam and is vented back to the cabin by the outlet three way valve (item 402 or 404) and the desorption diverter valve (item 406). After 1/2 to 2/3 of the amine bed has been heated, CO_2 also begins to leave the bed. This increases the total outlet flowrate.

The increased outlet flowrate is detected by the flow sensor (item 308) and the desorption diverter valve is switched to direct the CO_2 flow to the accumulator (item 203) and flow control. The accumulator stores part of the intermittently desorbed CO_2 so that a continuous flow of CO_2 can be supplied to a CO_2 reduction subsystem by the CO_2 flow control (items 408, 104 and 105). The CO_2 flow control subassembly can also be operated in a straight thru mode which does not require an accumulator. This is accomplished by opening the overboard dump valve (item 407).

The bed regeneration is complete when the temperature wave (steam) has completely passed thru the bed. This is detected by a rapid rise in bed outlet temperature (item 302 or 304). The flowrate of water is calculated to enable the desorbing bed to finish desorbing two minutes before the absorbing bed completes drying.

At the end of the absorb/desorb half-cycle an energy transfer is conducted. The object of the energy transfer is to transfer approximately 30 percent of the heat and moisture from the bed just completing desorption to the bed which is about to be desorbed. During energy transfer which lasts two minutes, the incoming process air is directed to the bed just completing desorption by either item 401 or 403. As the air moves thru the bed it is heated to the average bed temperature and is saturated with water. At the bed exit,the air is directed by either item 402 or 404 to the energy transfer valve (item 405), and from there it flows to the inlet of the bed just completing absorption.

As the air moves thru the second bed it is cooled and the excess water condenses in the bed. This raises the bed temperature and reduces the amount of energy which must be supplied to complete the desorption.

The subsystem was fabricated between September 1985 and February 1986. (Figures 1.0-2, 1.0-3 and 1.0-4).

The subsystem was tested for a total of 2500 hours while at Hamilton Standard's Windsor Locks, facility. This testing was broken into three distinct periods.

The first phase of testing accumulated 1300 hours of operation between March and July 1986. The major emphasis during this period was on checkout and adjustment of hardware, and subsystem performance was not evaluated. At the end of this test period the unit was shipped to JSC, Houston for display.

The second phase of testing followed the unit's return from Houston. This phase accumulated 1100 hours of testing between October 1986 and February 1987. The major emphasis during this phase was design evaluation. during this phase several different subsystem configurations and a new amine (WA21) were tested. At the end of this period the unit was refurbished and the design modifications resulting from the testing were incorporated.

The modified "as-delivered" subsystem is schematically presented on Figure 1.0-5 and pictorially on Figures 1.0-6 thru 1.0-8.

The changes consisted of moving the process air blower from the exit to the inlet and the elimination of the energy transfer valve. The process air blower was moved to take advantage of the lower relative humidity of the air at the blower discharge (due to temperature rise across the fan). This decrease in relative humidity made it easier to dry the beds and therefore maintain proper water loading in the beds. The energy transfer valve was eliminated after it was determined that the method of energy transfer discussed above resulted in increased amine degradation. Section 4.3.2 describes the changes in operation.

The third and final test phase accumulated 100 hours of operation during April 1987. The emphasis of the testing was final subsystem verification prior to shipping to Houston for testing in NASA/JSC's advanced ECS test facility.

Final performance was 0.127 Kg/hour (0.28 pph) CO_2 removal and 0.9 kg/hour (2.0 pph) H_2O (steam) for desorption and CO_2 pressurization.

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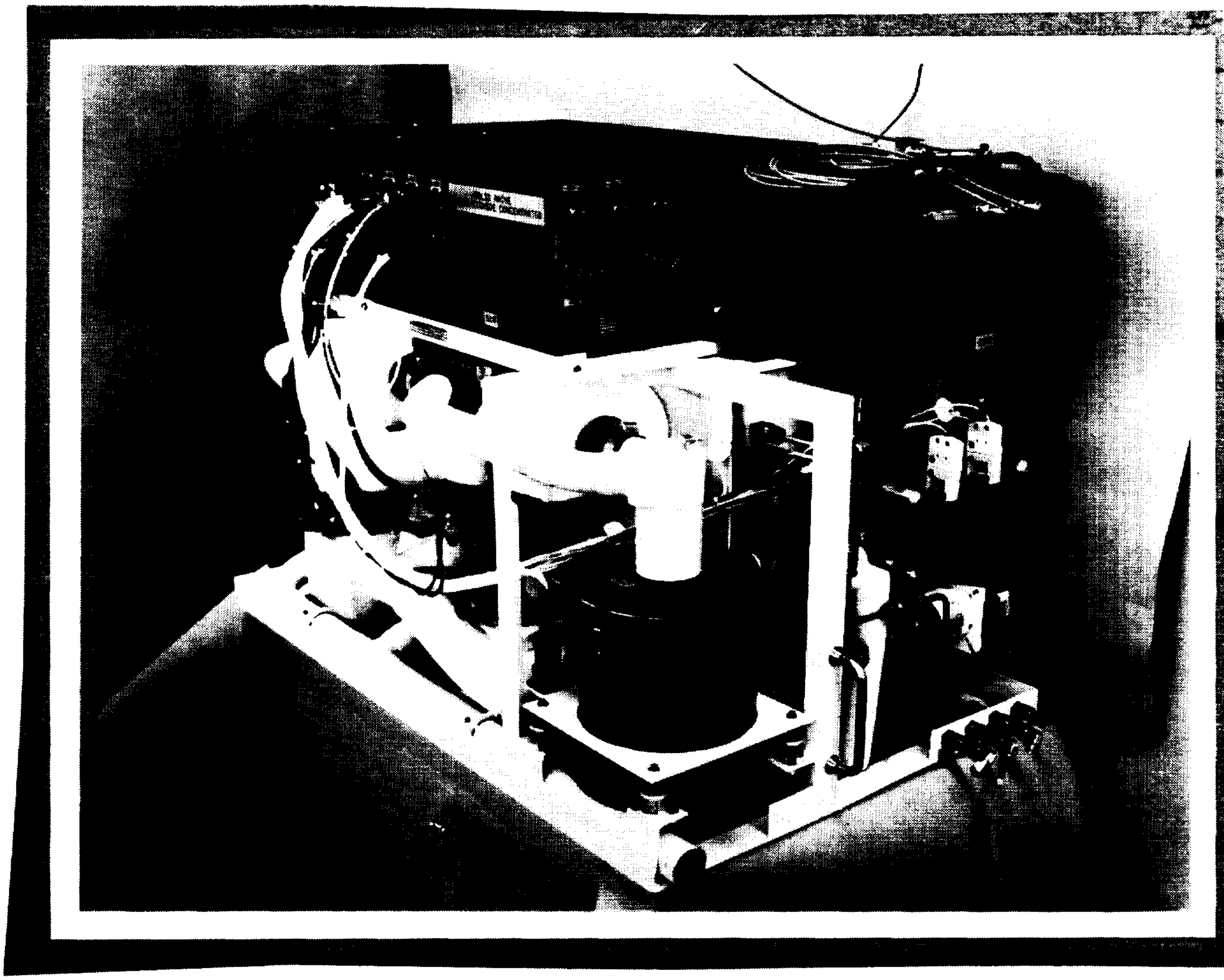

FIGURE 1.0-2
"AS-DESIGNED" SAWD II SYSTEM

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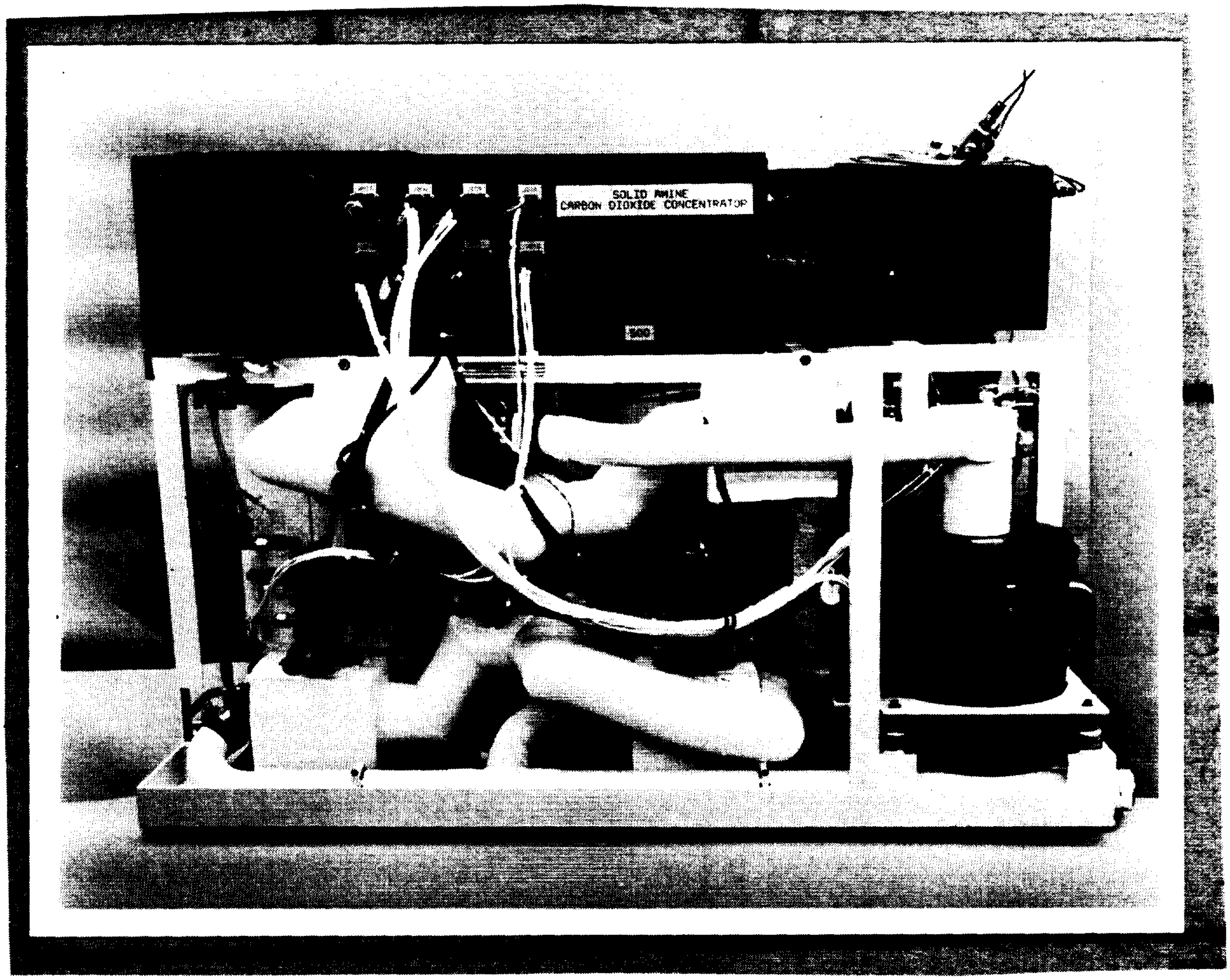

FIGURE 1.0-3
"AS-DESIGNED" SAWD II
FRONT VIEW

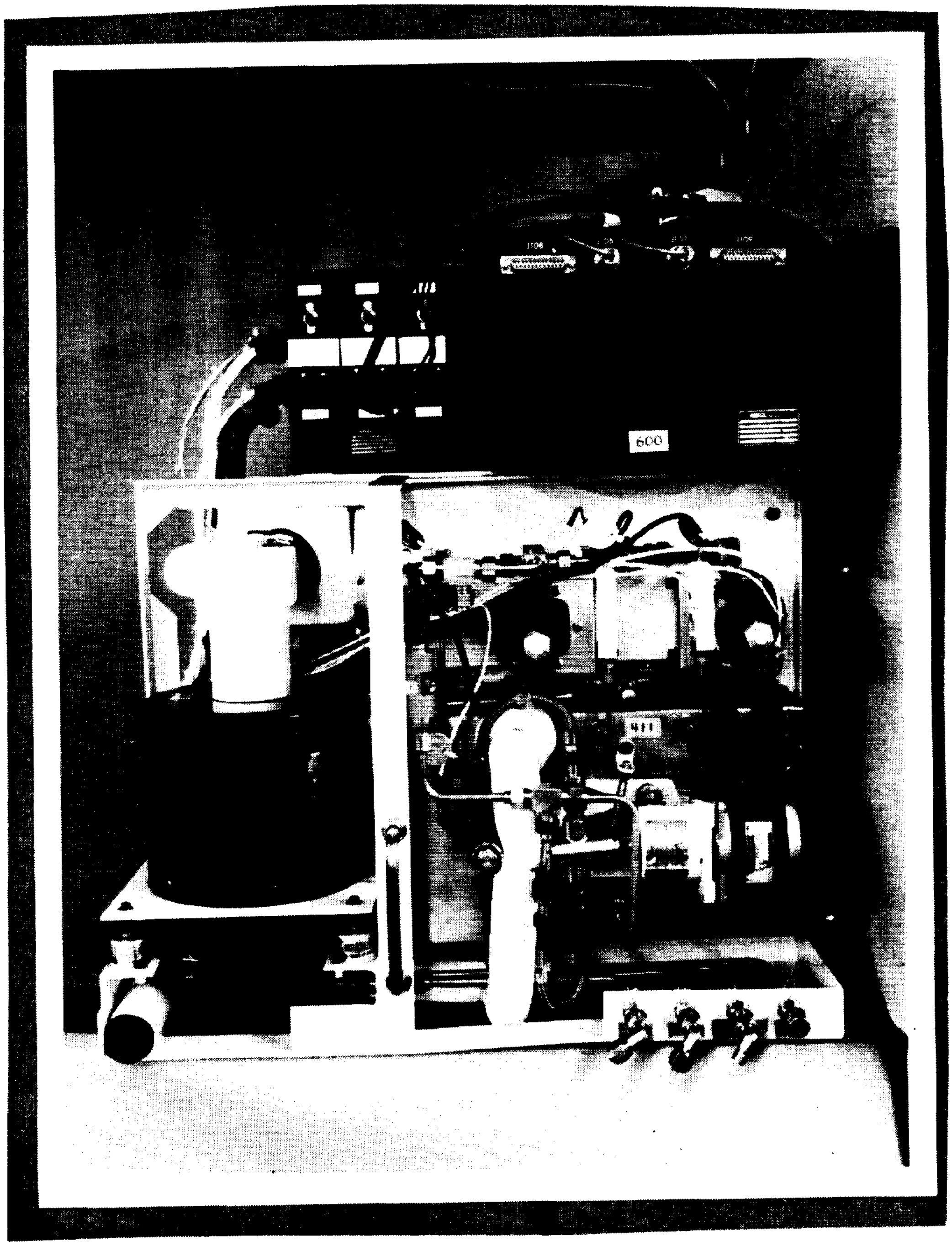

FIGURE 1.0-4
"AS DESIGNED" SAWD II
RIGHT SIDE

ITEM #	COMPONENT	ITEM #	COMPONENT
101	RELIEF VALVE	308	FLOW TRANSDUCER
102	CHECK VALVE	309	PRESSURE TRANSDUCER
103	BACKPRESSURE REGULATOR	401	CANISTER 1 INLET VALVE
104	PRESSURE REGULATOR	402	CANISTER 1 OUTLET VALVE
105	METERING VALVE	403	CANISTER 2 INLET VALVE
201	AMINE CANISTER #1	404	CANISTER 2 OUTLET VALVE
202	AMINE CANISTER #2	405	ENERGY TRANSFER VALVE (DELETED
203	ACCUMULATOR	406	DESORPTION DIVERTER VALVE
301	RESISTANCE THERMOMETER	407	CO_2 OVERBOARD VALVE
302	RESISTANCE THERMOMETER	408	CO_2 REDUCTION VALVE
303	RESISTANCE THERMOMETER	409	WATER SUPPLY VALVE
304	RESISTANCE THERMOMETER	410	WATER PUMP
305	RESISTANCE THERMOMETER	411	STEAM GENERATOR
306	RESISTANCE THERMOMETER	412	PROCESS AIR BLOWER
307	PRESSURE SWITCH	500	DRIVER BOX

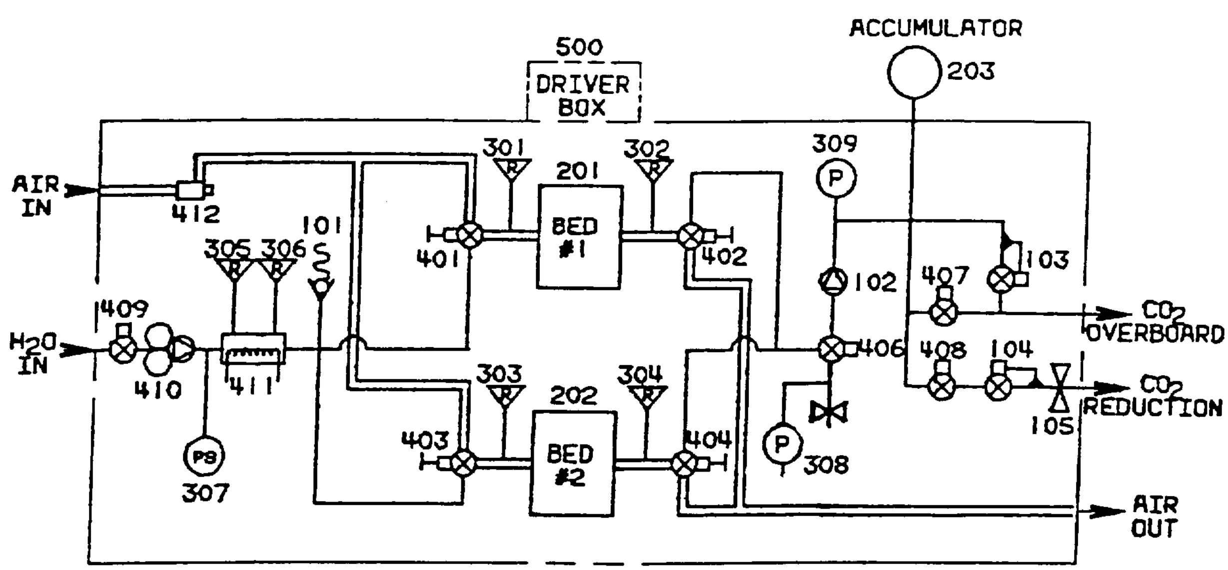

FIGURE 1.0-5
"AS DELIVERED" SAWD II SCHEMATIC DIAGRAM

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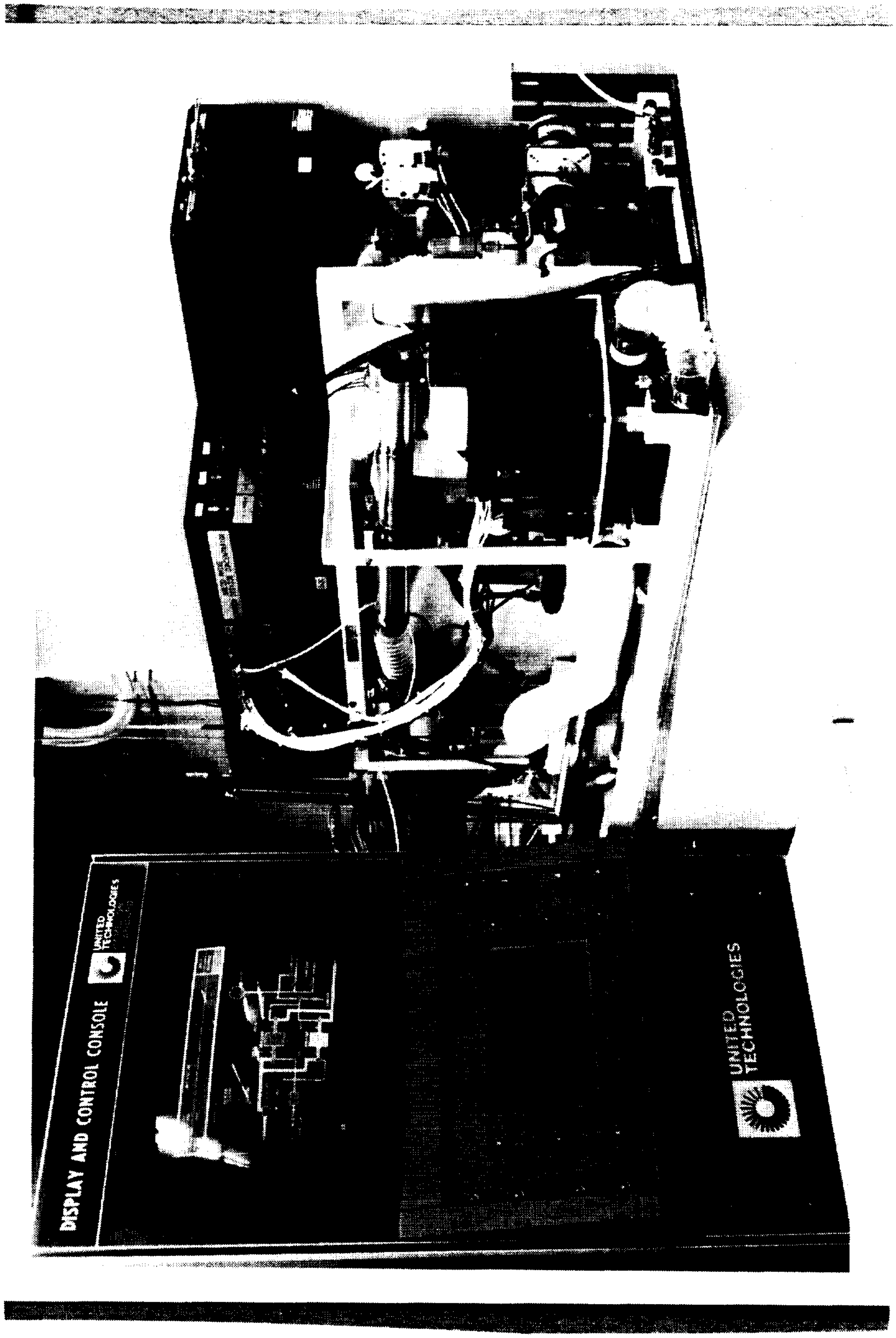

FIGURE 1.0-6
"AS DELIVERED" SAWD II SYSTEM

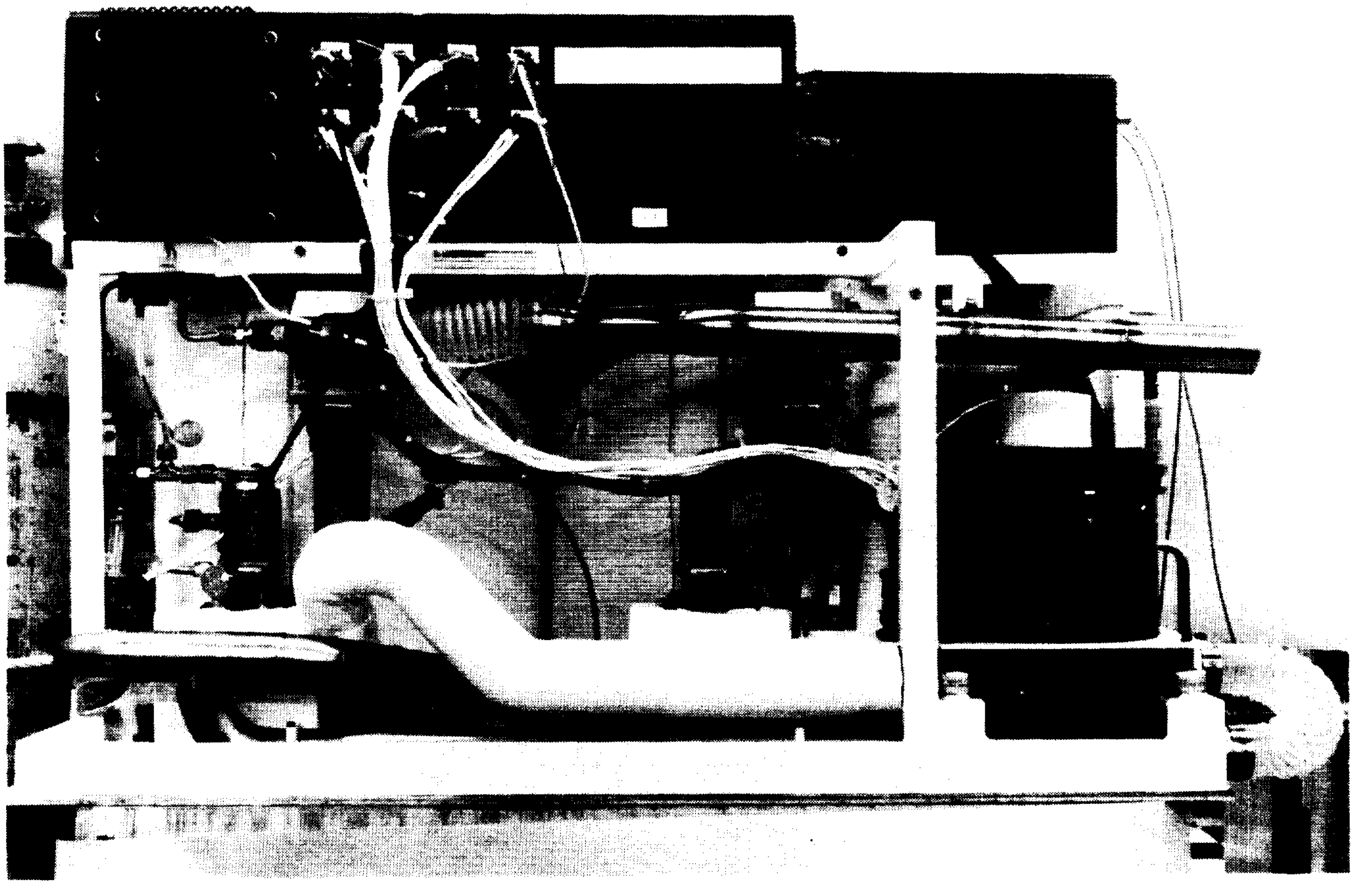

FIGURE 1.0-7
"AS DELIVERED" SAWD II
FRONT VIEW

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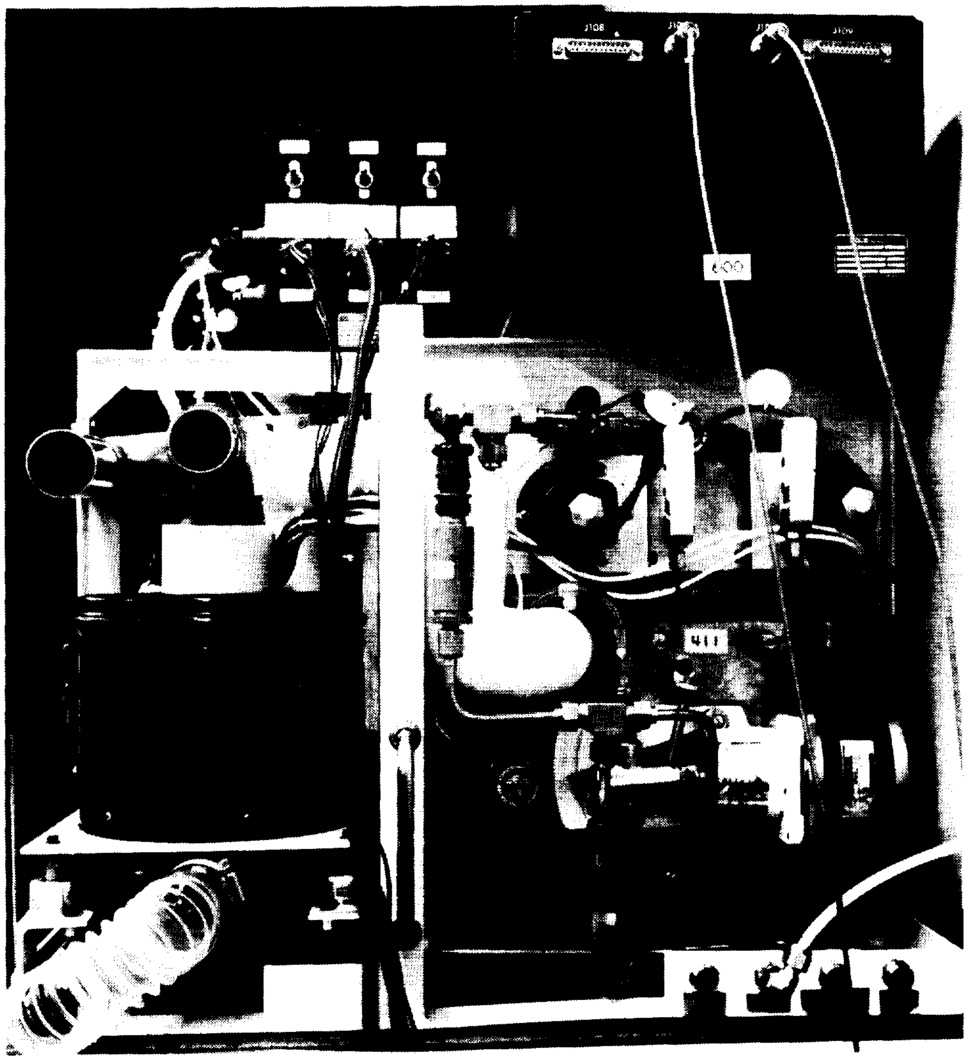


FIGURE 1.0-8
"AS DELIVERED" SAWD II
RIGHT SIDE

2.0 INTRODUCTION

Future, long-term manned space missions will require the utilization of regenerative Environmental Control Systems (ECS) to minimize weight, volume, and power. These regenerative ECS's must incorporate the capability of closing the oxygen loop to eliminate the need for oxygen resupply. Closing the oxygen loop in an ECS requires a method of removing CO_2 from the ambient atmosphere and delivering the CO_2 to a separate reduction subsystem where the oxygen can be reclaimed.

The use of a solid amine ion-exchange resin has been demonstrated to perform the CO_2 removal/delivery function under Contracts NAS 1-8944 and NAS 9-13624. The further development of the solid amine concept was continued under Contract NAS 9-16978, "Regenerable CO_2 and Humidity Control Systems". Major development goals of this program included lower average CO_2 partial pressure levels, reduction in power requirements, elimination of the CO_2 compressor required on earlier subsystems and demonstration of zero-gravity operation. This development program culminated in the fabrication and testing of the SAWD II subsystem.

The primary objective of this report is to present the results and conclusions of this testing. The report also reviews the analysis which led to the design and describes the subsystem design.

3.0 CONCLUSIONS AND RECOMMENDATIONS

The subsystem met the 3-man CO_2 removal and delivery goals. However, the range of operation was limited to cabin temperatures below 72°F and relative humidities between 35 and 50*. The limited range of operation resulted from modifications to the subsystem design that were made during the testing phase. These modifications were necessitated by two system shortcomings. The shortcomings were in the energy transfer technique and the subsystem thermal designs.

The original method of transferring energy utilized air to move between 20 and 30% of the moisture and energy from the bed just completing desorption to the bed just completing absorption. This method however, resulted in an increase in amine degradation due to oxidation and had to be discontinued. A modified energy transfer method which utilizes the pressure difference between the two beds was successful in removing approximately 10% of the total energy from the hot bed following desorption. The amount of energy transferred was limited by the difference between the final desorption pressure and ambient pressure.

Previous testing, in a Navy funded SAWD program, successfully transferred up to 40 percent of the moisture and energy from a hot bed following desorption. This testing was able to transfer more energy because the hot bed's pressure (thus it's saturation temperature) was reduced below ambient pressure. A similar condition can be achieved by evacuating the air from the cold bed (thus creating a partial vacuum). The two beds would then be allowed to equilibrate. It is recommended that this type of energy transfer be developed for future subsystem designs.

*Successful operation at temperatures up to 85°F and relative humidities of between 45 and 60% were demonstrated on a similar unit. However this testing required different computer software for automatic subsystem operation.

The subsystem thermal design resulted in a 25% higher desorption energy requirement than expected based on earlier SAWD breadboard testing. This loss is in addition to the 20% energy transfer shortfall. The high energy requirements were due to three design deficiencies. These deficiencies were the amine canisters insulation, the canister's amine retention screens and the canister's inlet valves.

The canister insulation had an air gap between the insulation and the canister's outer metal wall. This allowed convective air currents to carry heat from the hot bottom header to the inside of the entire insulation surface area. In addition, the inlet and exit lines, which penetrated the insulation, allowed air to enter and leave the air gap. This resulted in a chimney effect. Future insulation designs should use a "foamed-in-place" or a tightly wrapped type of insulation to reduce heat loss.

The present zero-g canister's amine-retention-screen subassembly weighs 1.4 kilograms (3 pounds). This is nearly two times the weight of previous one-g canister design. It is recommended that on future designs the retention screen subassembly be re-designed to reduce its weight. By reducing the weight the energy required to heat the assembly will be reduced.

The canister 3-way inlet valve is used to control both air and steam into the canister. This results in thermal cycling of the 900 gram (2 pound) valve. However, an even greater loss occurs when air flows thru the valve. With air flowing thru the valve, steam condenses on the back side of the valve. In order to avoid this problem on future designs it is recommended that one 3-way valve flow only steam (directing it to one or the other canister) and that a second 3-way valve flow only air. This will eliminate thermal cycling of valves. In addition the steam only valve can be smaller (1/4 inch steam lines versus 1 1/2 inch air lines). Furthermore, the line which separates the point where the air and steam tie together (see Figure 3.0-1), will have a dead insulating air space between the steam flow and the air flow.

Due to these shortcomings the design goal of reduced power consumption was not achieved.

In addition to the thermal problems on the canister inlet valve, the valve also had a leakage problem after 1200 hours and had to have the seal replaced. This problem resulted from the high temperature operation of the valve and from the cyclic operation of the seal (first the seal must keep the high pressure steam out of the valve and then it has to keep it in the valve). The same problem was observed on a similar unit three times at between 1000 and 1300 hours. The problem was finally corrected by the addition of a separate steam flow control valve as recommended above. The other unit has accumulated over 8000 hours since the modification without a leakage problem.

The subsystem did demonstrate the ability to operate at zero-gravity. The amine canister bellows successfully prevented the amine from being fluidized while also providing adequate expansion of the amine due to changes in bed moisture content.

Although the amine demonstrated similar performance with either air flowing up or down thru the bed, it is recommended that on future subsystem designs that the air and steam flow in opposite directions instead of the same direction as was done on SAWD II. This will result in a cooler bed and a lower decay rate.

The subsystem also demonstrated that concentrated CO_2 at a purity of 99% (dry base) can be delivered to an accumulator at up to 200 KP (30 psia) without a CO_2 compressor.

A schematic which incorporates the above recommendations as well as several other enhancements (ullage air compressor for increased energy transfer and dual steam generators) is presented in Figure 3.0-1.

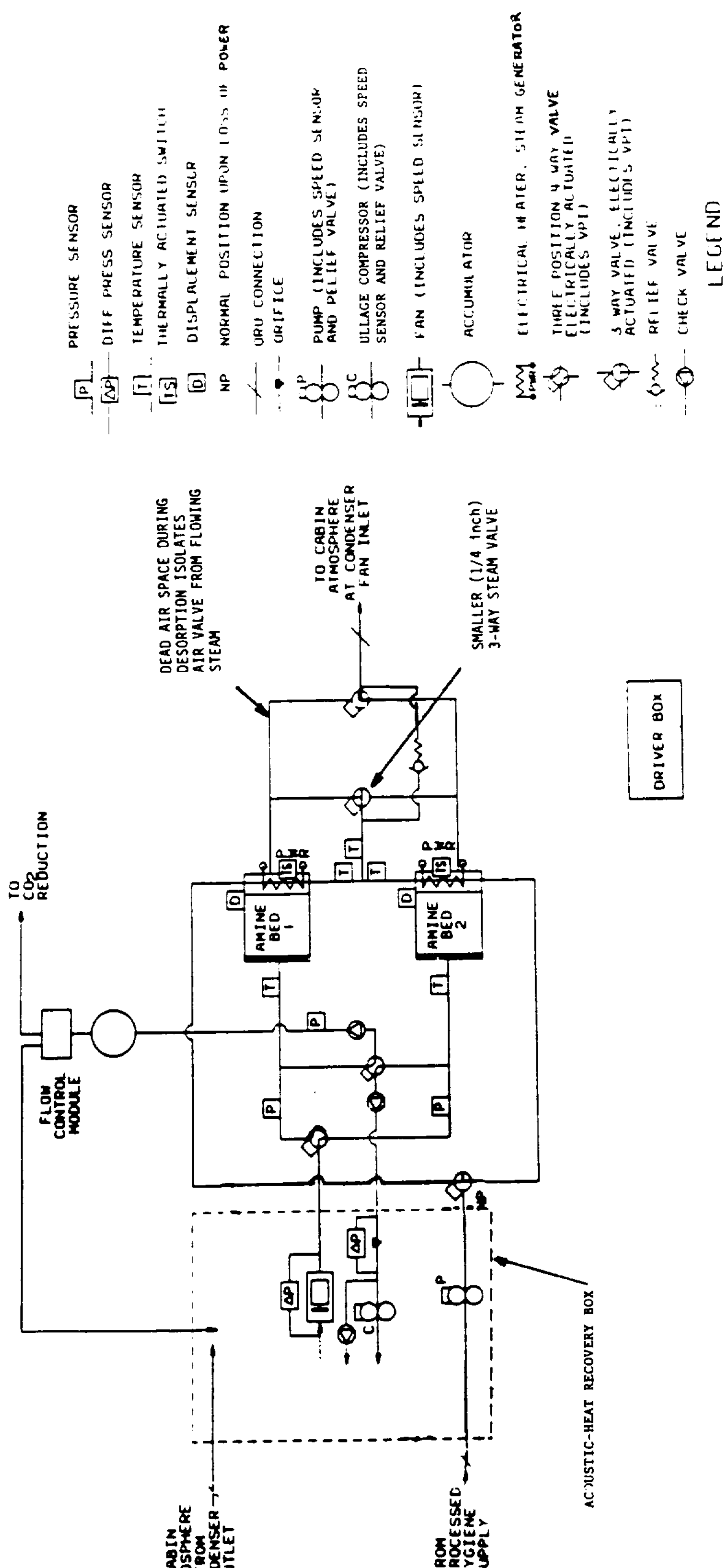


FIGURE 3.0-1
SAWD II SYSTEM SCHEMATIC
"PROPOSED (FUTURE)"

4.0 DISCUSSION

This section describes the analysis, design, hardware, and testing of the preprototype solid amine, carbon dioxide (CO_2) removal subsystem. The subsystem incorporates two zero-gravity solid amine canisters (beds) for CO_2 removal; a zero-gravity steam generator for bed regeneration (desorption), CO_2 concentration and CO_2 compression; an accumulator and various valves for CO_2, storage/delivery; and a microprocessor for automatic subsystem control and to interface with the Display and Control Console (DCC). *

The discussion is broken down as follows:

a. Section 4.1, System Analysis
b. Section 4.2, Component Design
c. Section 4.3, Subsystem Description & Operation
d. Section 4.4, Performance Testing

4.1 System Analysis

This section describes the analyses that were conducted to select the optimum system concept for the second generation preprototype subsystem. The study considered a total of seven candidate concepts which included systems with two, three and four canisters.

* The DCC is a preprototype man/machine interface subsystem which was developed by Hamilton Standard to simultaneously control several environmental control and life support (ECLS) subsystems. Additional information about the DCC can be found in the SAWD II Installation and Operation Manual (SVHSER 10633).

4.1 (Continued)

The system candidates were analyzed for the following operating conditions and performance requirements.

Operating Conditions

Inlet CO_2 Level	3.0 mm Hg
Ambient Pressure	14.7 psia
Relative Humidity Range	35 to 70%
Inlet Temperature Range	65 to 80°F

Performance Requirements

CO_2 Removal/Delivery Rate	0.275 lb/hr
CO_2 Delivery Pressure	18.3 psia
Allowable Envelope	(10.3 ft^3)

4.1.1 Results of Trade Studies

The following five basic SAWD system concepts were evaluated for comparison.

Concept	Description
A	Two canisters with an accumulator
B	Three canisters without an accumulator
C	Two canisters without an accumulator
D	2-Two canister systems (4 canisters total) without an accumulator
E	1-Four canister system without an accumulator

4.1.1 (Continued)

In addition, the merits of desorption at three distinct pressure levels (and therefore three distinct desorption technique concepts) were evaluated. The three desorption techniques were:

(1) Ambient pressure (14.7 psia) desorption, with a CO_2 compressor used to supply CO_2 pressurization.

(2) Reduced pressure (5.0 psia) desorption which allowed desorption at 160°F to reduce the thermal energy requirement, also uses CO_2 compressor.

(3) Elevated pressure (30.0 psia) desorption which utilized the steam generator to compress the CO_2 and therefore eliminated the compressor from that concept.

The five concepts and three desorption techniques yield a potential fifteen different system combinations. However to minimize the analytical effort, it was decided to evaluate the five basic candidate concepts on a common desorption basis (ambient pressure desorption - 14.7 psia) and to make a relative comparison of power, weight and volume for each system.

Because the least power, weight, and number of components occurred for the two-canister system that incorporated an accumulator, only this system was evaluated for different desorption pressures. Since the weight, power and volume for these three concepts were nearly the same, a failure rate analysis and development cost estimate was also done to select the most promising configuration.

Figure 4.1-1, 4.1-2 and 4.1-3 present schematics of the candidate systems. Additional discussion of how the candidate systems function is provided in Section 4.1.2.

4.1.1 (Continued)

Table 4.1-1 summarizes the system comparison (on the basis of flight system penalties for weight, volume, and nominal power) for the seven candidate concepts at nominal (50% relative humidity) operating conditions. The table shows that all seven concepts easily fit within the specified envelope and are significantly smaller than the envelope volume (10.3 ft^3) with a volume range from 4.9 to 7.4 ft^3. The concept weight estimates vary from 106 lbs for the two-canister, accumulator concept that is desorbed at 14.7 psia (Concept A2, Figure 4.1-1) to 149 lbs for the four-canister (2 two-canister systems operating in combination) candidate (Concept D, Figure 4.1-3). The lowest levels of power (435 to 455 watts) resulted for the two-canister concepts that incorporated an accumulator (Concepts A1, A2, and A3). The least system components also occurred for the two-canister concepts. (Concepts A1, A2, A3, and C).

The results of the failure rate analysis is presented in Table 4.1-2. These results were then ranked along with the other selection criteria (cost, power weight, volume). A basic numerical ranking system (1, 2, 3, . . .n), with the lowest number representing the best concept, was applied to each trade criterion. The criteria were ranked proportionally in order of the lowest through the highest quantity. For example, the concept with the lowest power consumption was ranked 1, concepts with higher power consumption were assigned rankings increased by 1 unit for each 15 percent power consumption increase over the lowest power consumption. The result of this ranking are as follows:

4.1.1 (Continued)

Concept Ranking

Criterion	Concept (Two Canisters With Accumulator)		
	A1	A2	A3
Cost	2	3	1
Failure Rate	5	3	1
Power	1	1	1
Weight	2	1	1
Volume	1	1	3
Score	11	9	7

The two-canister with accumulator system (Concept A3), which incorporates desorption of 30 psia, was selected for design and development as a result of its lowest ranking score of seven (7).

TABLE 4.1-1

SAWD CONCEPT COMPARISON

50% RH NOMINAL CONDITIONS

FLIGHT SYSTEM BASIS

CONCEPT	CANISTERS	DESORPTION PRESSURE (psia)	ACCUMULATOR	COMPONENTS	NOMINAL POWER (watts)	WEIGHT (lb)	VOLUME (ft^3)
A1	2	5.0	YES	31	455	125	6.22
A2	2	14.7	YES	24	435	106	5.87
A3	2	30.0	YES	23	454	113	7.43
B	3	14.7	NO	33	847	128	5.07
C	2	14.7	NO	28	525**	122	6.02
D	2 + 2	14.7	NO	23 + 23	616	149	5.50
E	4	14.7	NO	42	651	139	4.88

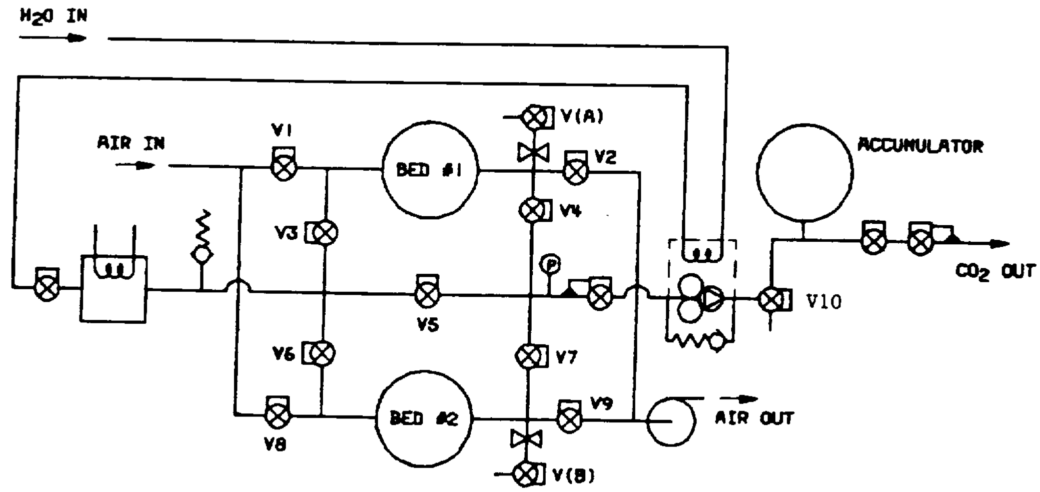
*All concepts fit within the allowable envelope (24 X 24 X 31 in.).

**845 watts during period (i.e., 1/3 of total cycle) that two canisters are desorbing.

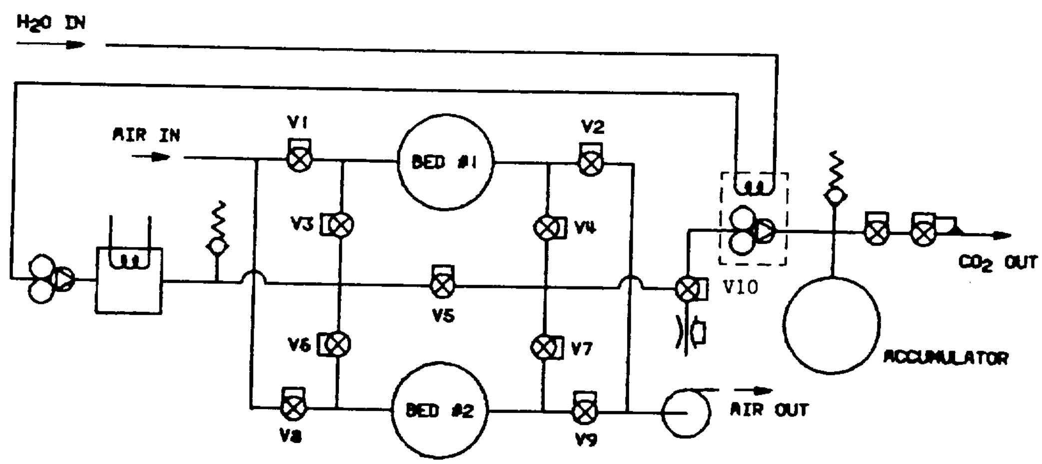
TABLE 4.1-2
FAILURE RATE SUMMARY
NUMBER OF COMPONENTS IN EACH SCHEMATIC

COMPONENT	CONCEPT A1	CONCEPT A2	CONCEPT A3	FAILURE RATE (Per Million Hrs)
Two-Way Solenoid Valve	13	10	10	1.640
Three-Way Solenoid Valve	1	1	1	2.671
Regulator	2	1	2	2.857
Pressure Sensor	1	0	1	2.329
Orifice	2	0	0	0.160
Accumulator	1	1	1	0.010
Relief Valve	2	2	1	0.675
Heater	1	1	1	0.450
Beds	2	2	2	0.550
Blower	1	1	1	2.518
Compressor	2	1	0	10.89
Pump	0	1	1	4.219
Flow Switch	0	1	1	2.428
Total Failure Rate:	61.562	46.893	40.514	

CONCEPT A1 - 5 PSIA DESORB



CONCEPT A2 - 14.7 PSIA DESORB



CONCEPT A3 - 30 PSIA DESORB

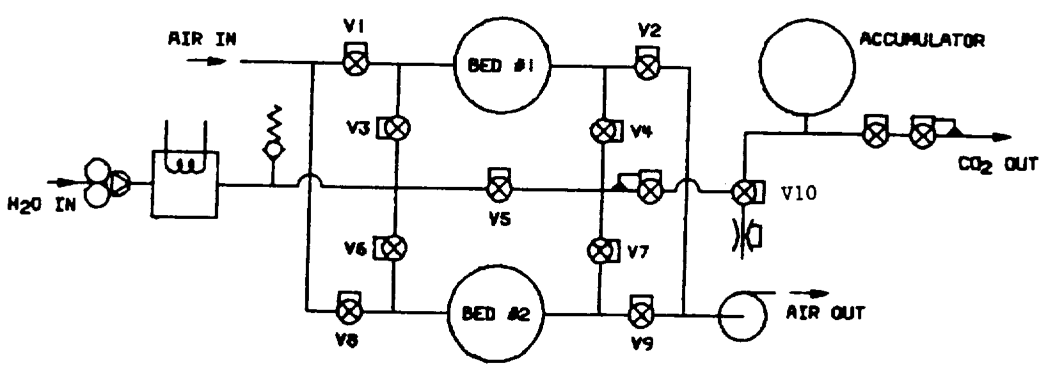
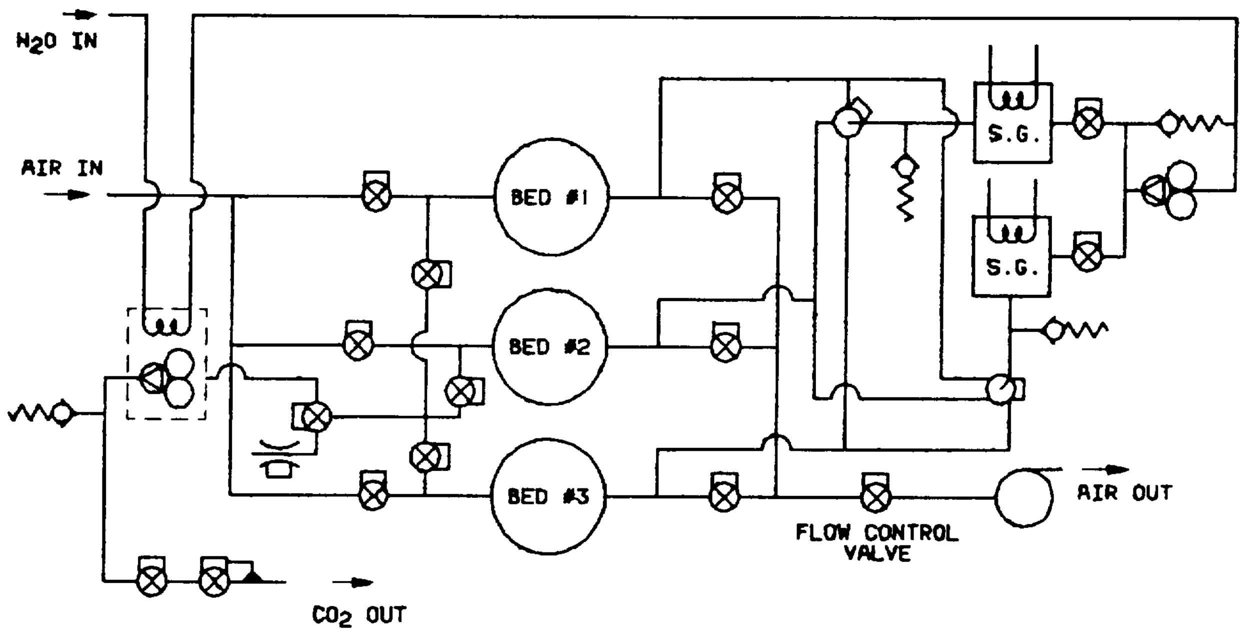


FIGURE 4.1-1
SUBSYSTEM CONCEPTS A1-A3

CONCEPT B



CONCEPT C

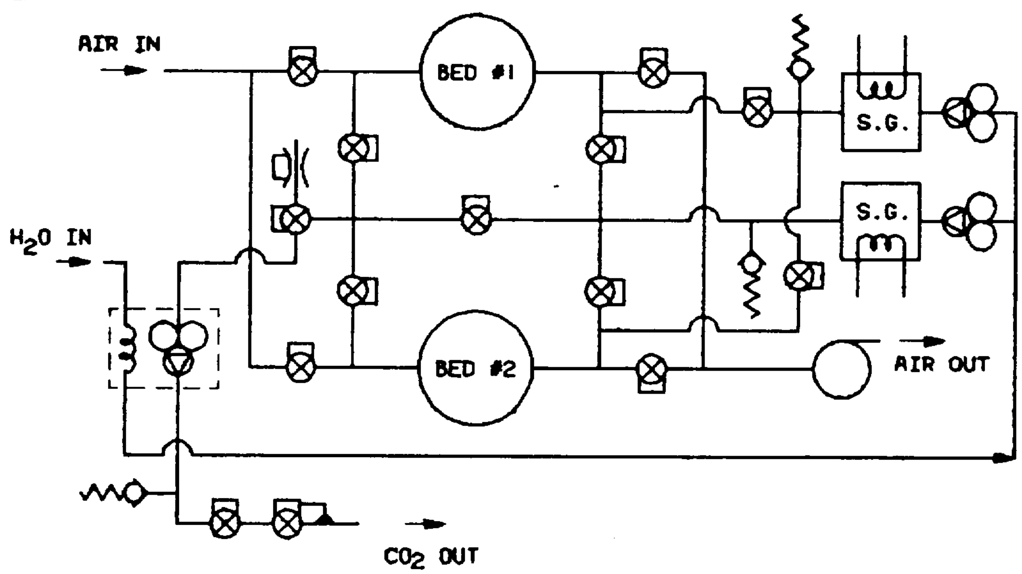
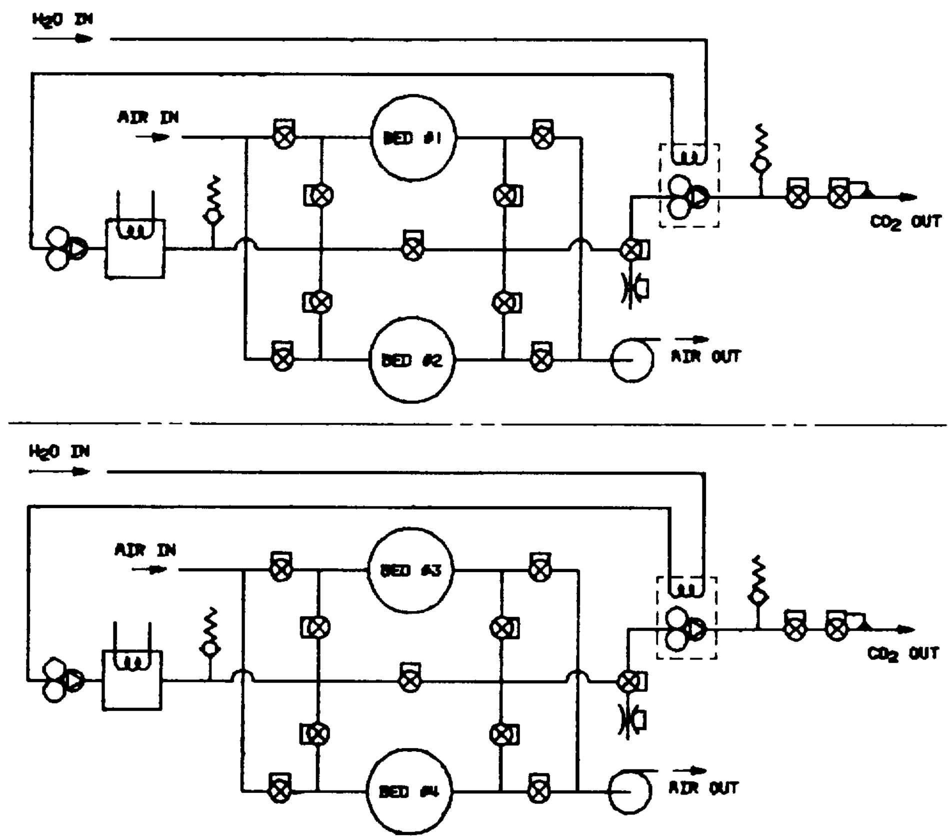


FIGURE 4.1-2

SUBSYSTEM CONCEPTS B AND C

CONCEPT D



CONCEPT E

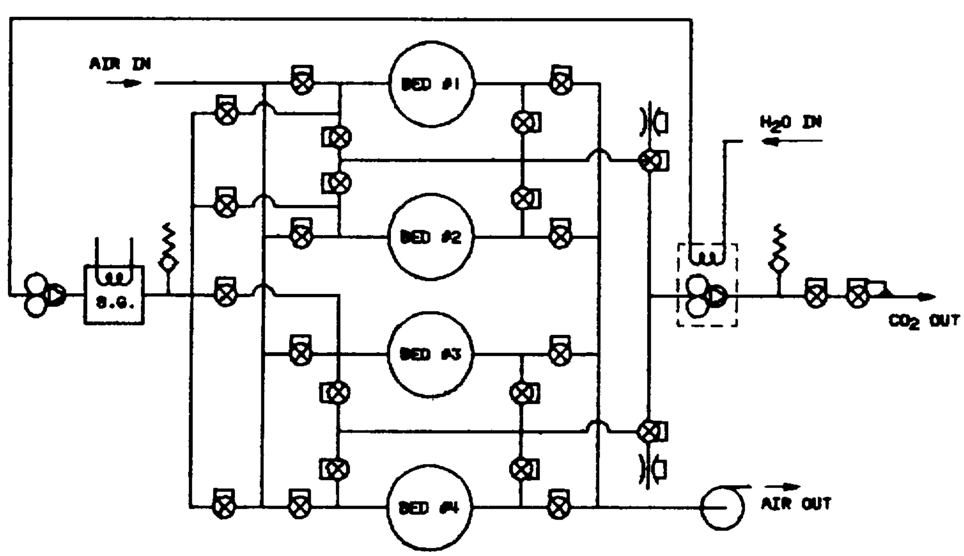


FIGURE 4.1-3

SUBSYSTEM CONCEPTS D AND E

4.1.2 Description of Candidate Subsystems

During absorption, the process air blower moves atmospheric air through the absorbing canister. In addition to removing CO_2 during absorption, the resin bed also humidifies the air stream. This process eliminates the heat of CO_2 absorption and permits the water, which was added during the previous desorption, to be removed, thereby maintaining a stable bed water loading. The length of the absorption time is determined by how quickly the air can remove the water (i.e., relative humidity and flow rate of air).

During the first part of desorption, the CO_2 diverter valve is positioned to allow any trapped air to leave the canister through the flow transducer. This stage is considered complete when the CO_2 begins to leave the canister and the resulting increase in flow is sensed by the flow transducer. Refer to Figure 4.1-4. The subsystem controller then repositions the CO_2 diverter valve to direct the flow to the accumulator or CO_2 reduction subsystem. CO_2 delivery to the atmosphere revitalization system can be accomplished either by direct feed from the desorbing SAWD canister or by regulated feed from an accumulator unit (which collects and stores the CO_2 during desorption). Utilization of an accumulator in the SAWD system has two significant advantages over direct CO_2 feed from the canister during desorption. First, the power requirement is minimized with an accumulator because no additional (peak) power is applied to hasten the onset of CO_2 evolution. Second, fully controlled CO_2 delivery (and therefore minimized CO_2 waste) can more readily be accomplished from an accumulator unit.

Figure 4.1-5 presents the fraction (percent) of the total desorption energy required to initiate CO_2 flow as a function of the CO_2 loading on the bed. This figure shows that a bed with less than 3% CO_2 loading requires more than 50% of the total desorption energy before CO_2 begins to leave the bed. Assuming a constant steaming rate, this means that CO_2 will be delivered from the bed for only 40% of the desorb time.

4.1.2 Description of Candidate Subsystems (Continued)

Figure 4.1-6 shows the power penalty required to shorten the time before the onset of CO_2 flow (i.e., higher steam flow). For example, Figure 4.1-4 shows that a bed with 2.0% CO_2 loading normally provides CO_2 flow over 30% of the desorption cycle and 70% of the desorption energy is required to initiate the CO_2 flow. Figure 4.1-5 shows that about 200% of the normal desorption power is required to increase the CO_2 flow duration from 30% of the desorb cycle to 67% of the cycle.

This increased power demand becomes worse as the CO_2 loading decreases or as the desired CO_2 flow duration increases. An accumulator accepts the CO_2 as it is evolved and allows the desorption power to be only secondarily dependent upon CO_2 loading and is independent of CO_2 flow duration. The controlled delivery of CO_2 directly from the canister during desorption is sensitive to power level, as can be observed from Figure 4.1-7. Further, a CO_2 delivery rate of 0.275 lb/hr is only about 0.034 cfm and therefore, needs only about 100 watts of power to sustain that level of CO_2 evolution. However, between four to ten times that power level is needed to accelerate the initiation of CO_2 flow. Because of that power level fluctuation, excessive CO_2 delivery rates are expected for some period during each cycle. Significantly simpler control of the CO_2 delivery rate can be achieved with an accumulator unit.

4.1.2.1 Two-Canister Systems

Both two-canister concepts (Concepts A and C) are shown functionally in Figure 4.1-8 and by schematic in Figures 4.1-1 and 4.1-2.

The systems that include an accumulator (Concepts A) were evaluated for equal absorption and desorption cycle durations, as is shown in Figure 4.1-8. The accumulator size is minimized where the CO_2 desorption flow occurs over the longest period of time. However, approximately two-thirds of the desorption cycle appears to be the practical average time limit for CO_2 delivery from the canister and the accumulator was sized for that CO_2 delivery period.

4.1.2.1 Two-Canister Systems (Continued)

The two-canister system without an accumulator (Concept C) incorporated a desorption cycle that was twice the length of the absorption duration to permit constant CO_2 delivery. The CO_2 flow was selected to occur during two-thirds of the desorption cycle, as it did for the two-canister concept with an accumulator. This concept does not provide full-time absorption and accordingly does not maintain a constant cabin ambient CO_2 level.

4.1.2.2 Three-Canister System

This concept (Concept B) is shown functionally in Figure 4.1-9 and by schematic in Figure 4.1-2. This system absorbs constantly to maintain a constant ambient CO_2 level and was evaluated for CO_2 flow over two-thirds of the desorption duration.

4.1.2.3 Four-Canister Systems

Both four-canister concepts (Concepts D and E) are shown functionally in Figure 4.1-10 and their schematics are included in Figure 4.1-3. The concepts permitted CO_2 flow over 50% of the desorption cycle and were evaluated accordingly. Concept E is a completely integrate four-canister system. Concept D is comprised of two, two-canister systems operating together as a unit. These systems incorporate full-time absorption and maintain a constant cabin CO_2 level.

4.1.2.4 Ambient Pressure Desorption

This system, illustrated by the Concept A2 schematic, Figure 4.1-1, operates at ambient pressure (14.7 psia) in both the absorption and desorption modes. The regeneratively-cooled compressor, which operates only during that portion of the desorption cycle when CO_2 is evolving from the amine, delivers the excess CO_2 flow to the accumulator for storage. Compressor operation is

4.1.2.4 Ambient Pressure Desorption (Continued)

initiated by a signal from the flow meter which indicates that CO_2 evolution has begun. The regenerative cooling to the compressor is provided by the desorption water, prior to use as the desorption fluid, to minimize the system power requirement. This concept also incorporates air exchange to reduce the desorption power penalty by 20%. The transfer of energy via air exchange from one canister to the other is accomplished by flowing air through both canisters, in series, in the following manner. When one canister completes absorption (and is ready to be desorbed), the other canister has just completed desorption (and is ready to begin absorption). For explanation purposes, Bed #1 (reference Concept A2, Figure 4.1-1) has just completed desorption and is ready to begin absorption. Bed #2 has just completed absorption and is ready to be desorbed. For a brief period (about two minutes), air flows through the path created by opening the following valves: V1, V4, V5 V6 and V9. During this period, V2, V3, V7 and V8 are closed. The air is heated to a hot moisture-saturated condition by Bed #1, and this energy and moisture are transferred to Bed #2 to effect the air exchange energy transfer. Upon completion of this energy exchange, V2 opens and V4 and V5 close to allow absorption of Bed #1 to continue in the normal mode with flow from the air inlet, through V1 and V2, through the fan, and returned to the cabin. Simultaneously, V7 opens (V6 is open) and steam flow through V6 to Bed #2 begins. Trapped air is vented through the flow meter (to the cabin) until the onset of CO_2 flow begins, then CO_2 is directed to the accumulator or the CO_2 outlet. Desorption of Bed #2 continues to completion, then the operating modes are again reversed.

4.1.2.5 Reduced Pressure Desorption

This system, illustrated on the Concept A1, Figure 4.1-1 utilizes a compressor to reduce the canister pressure to 4.0 psia prior to the initiation of steam flow to accomplish desorption at 160°F. The compressor incorporates regenerative cooling, by the desorption water prior to flow to the steam generator, to minimize the system power requirement. The sequential operation (with absorption at 14.7 psia and desorption at 5.0 psia) of this concept is summarized as follows:

4.1.2.5 Reduced Pressure Desorption (Continued)

(1) Bed #1 has just completed desorption at 4.0 psia and Bed #2 has just finished absorption at 14.7 psia. Each bed is now ready to reverse the mode of operation and pressure level.

(2) The CO_2 outlet line from Bed #1 closes (V4 closes).

(3) The CO_2 outlet line for Bed #2 opens (V7 opens) and the compressor pumps down Bed #2. Air from Bed #2 exhausts to ambient through V10.

(4) When Bed #2 pressure reads 5.0 psia, V(A), V3, and V6 open (V7 is open) to permit the air exchange energy transfer from Bed #1 to Bed #2.

(5) After completion of the air exchange, Bed #1 is returned to 14.7 psia and begins absorption (V(A) and V3 close; V1 and V2 open). Bed #2 begins steam desorption at 5.0 psia and continues (in a manner similar to that for Concept A2) until desorption is completed.

(6) The canisters again reverse operating modes.

4.1.2.6 Elevated Pressure Desorption

This system, illustrated by the Concept A3, Figure 4.1-1, operates at 14.7 psia in the absorption mode and at 30 psia during desorption. The compressor is eliminated from this candidate and compression of the CO_2 is provided by the steam generator. Operation of this system proceeds in the following manner: Bed #1 has completed desorption (and is ready to resume absorption) and Bed #2 has just completed absorption (and is ready to be desorbed). Valves (V4, V5 and V6) are opened, with all other valves closed, to equalize the canister pressure. V1 and V9 are then opened and the fan turned on to accomplish the energy transfer via air exchange. As for Concept A2, the air exchange duration is in the order of two minutes. Bed #1 then begins absorption by closing V4 and opening V2. Desorption of Bed #2 continues by closing V5 opening V7 (V6 is open), and flowing steam at 30 psia to the canister. Trapped air in Bed #2 is vented to ambient through V10 until the flow meter indicates CO_2 evolution from the bed. The CO_2 is then directed to the accumulator or to the CO_2 outlet. Desorption of Bed #2 continues to completion, then the operating modes are again reversed.

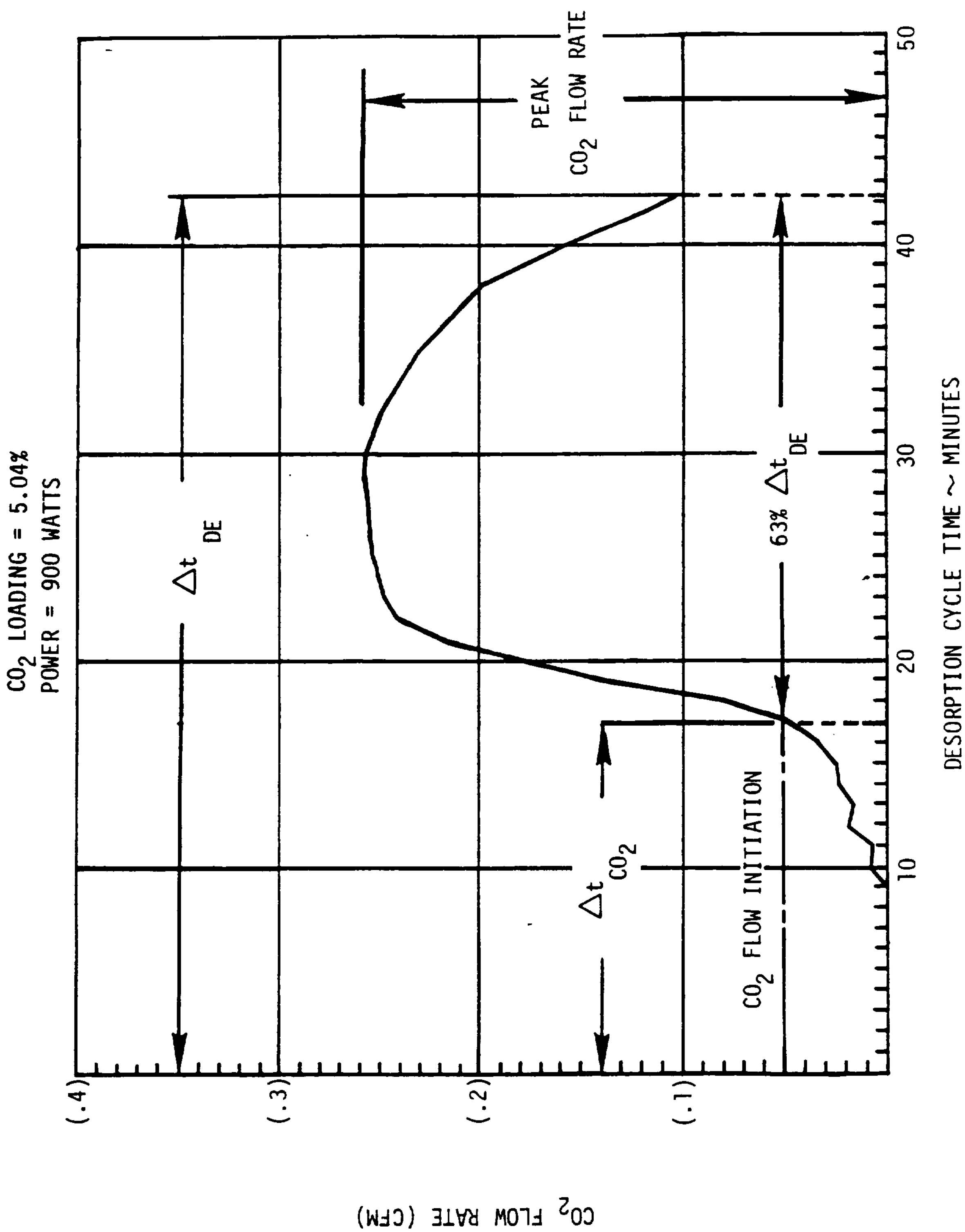


FIGURE 4.1-4
TYPICAL DESORPTION FLOW PROFILE

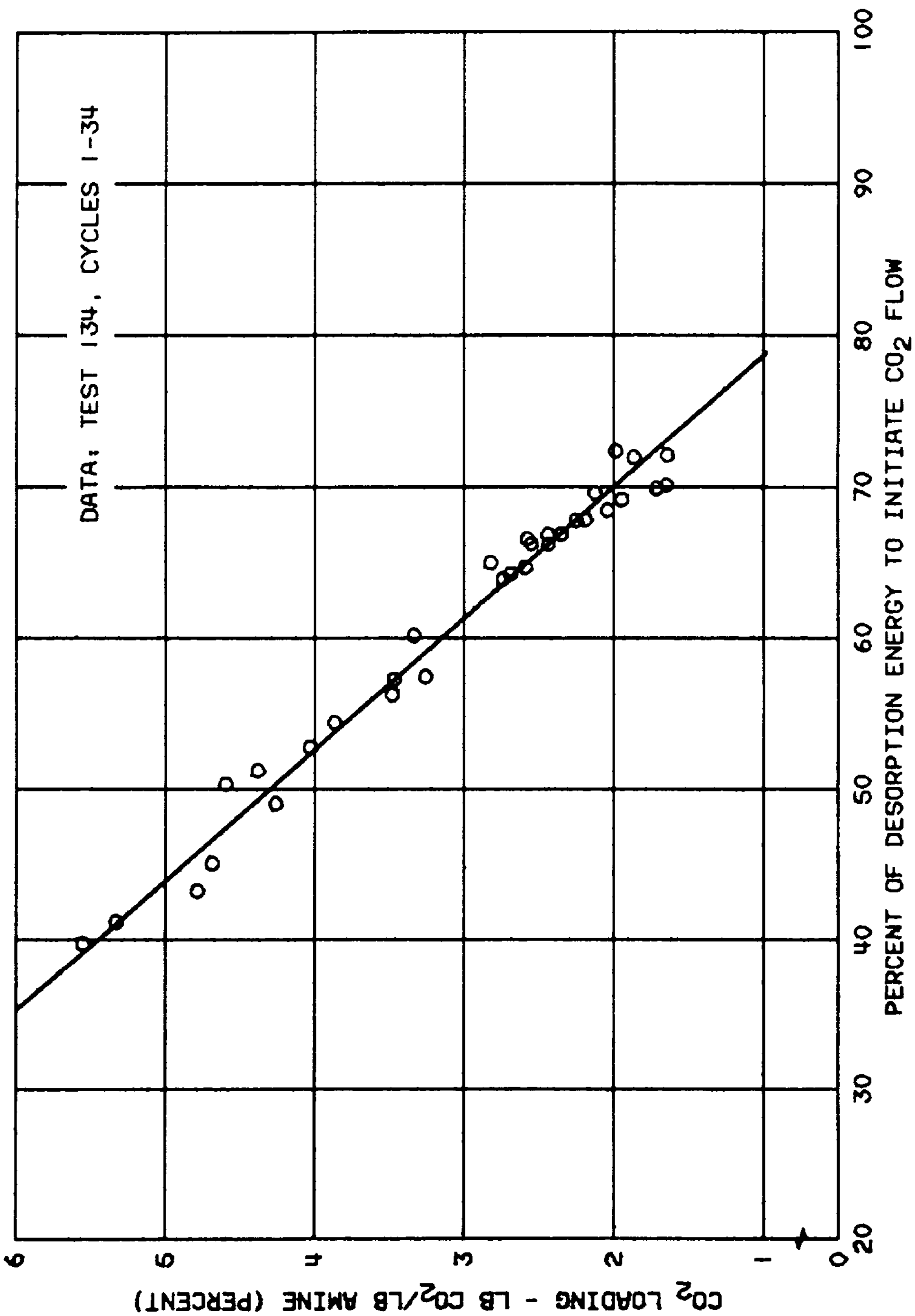


FIGURE 4.1-5

PERCENT CO_2 LOADING vs PERCENT ENERGY TO INITIATE FLOW

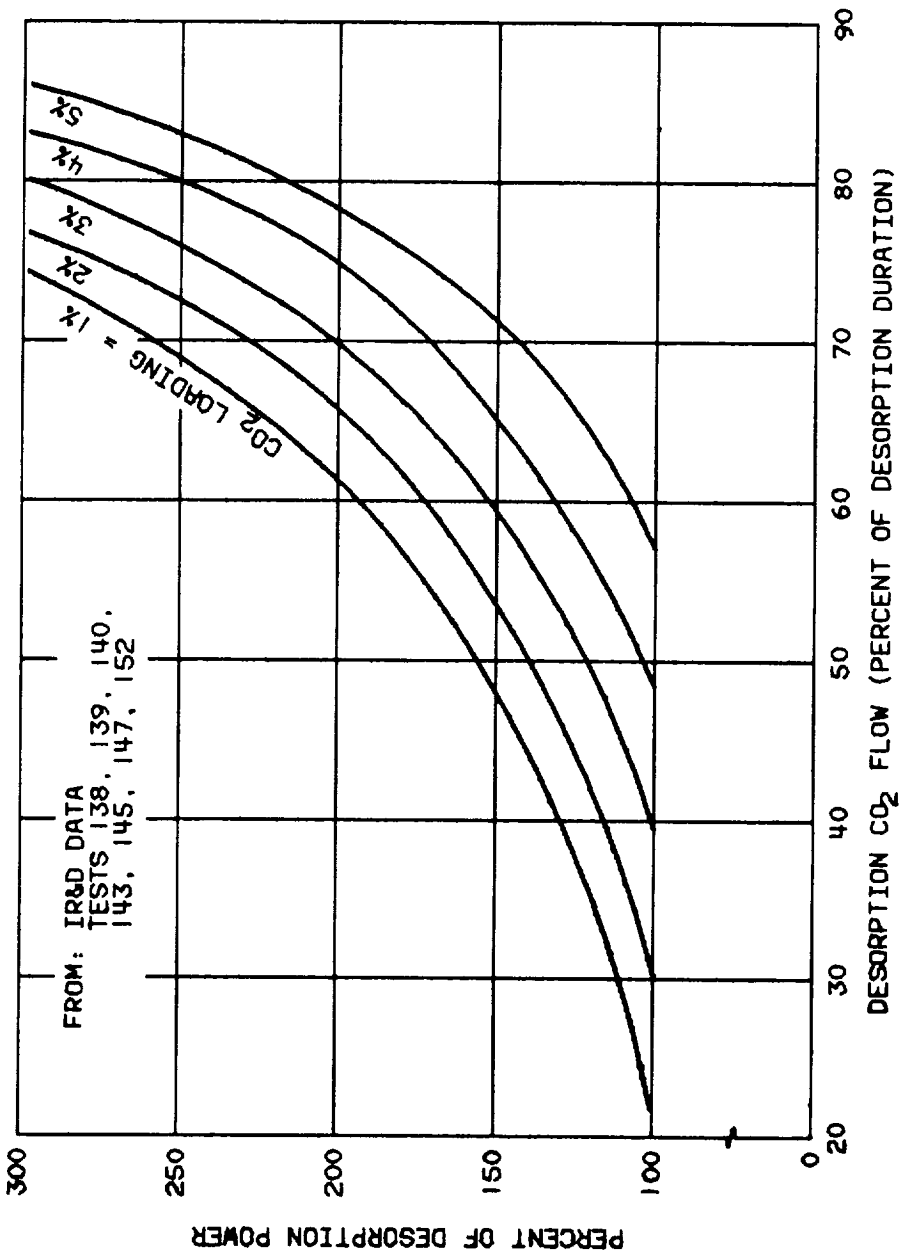


FIGURE 4.1-6
PERCENT DESORB POWER vs PERCENT DESORB DURATION

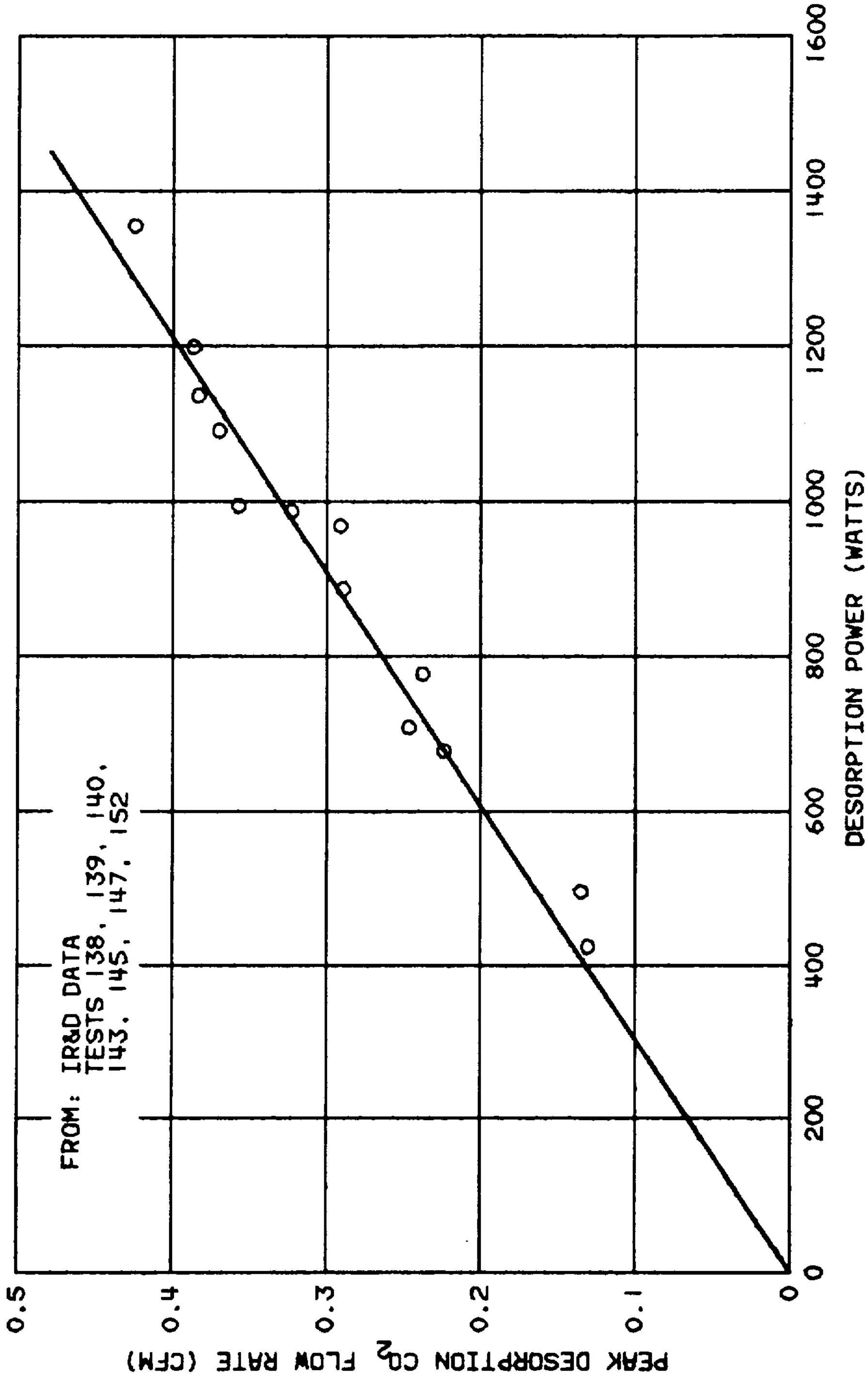


FIGURE 4.1-7
PEAK DESORB CO_2 FLOW RATE vs DESORB POWER

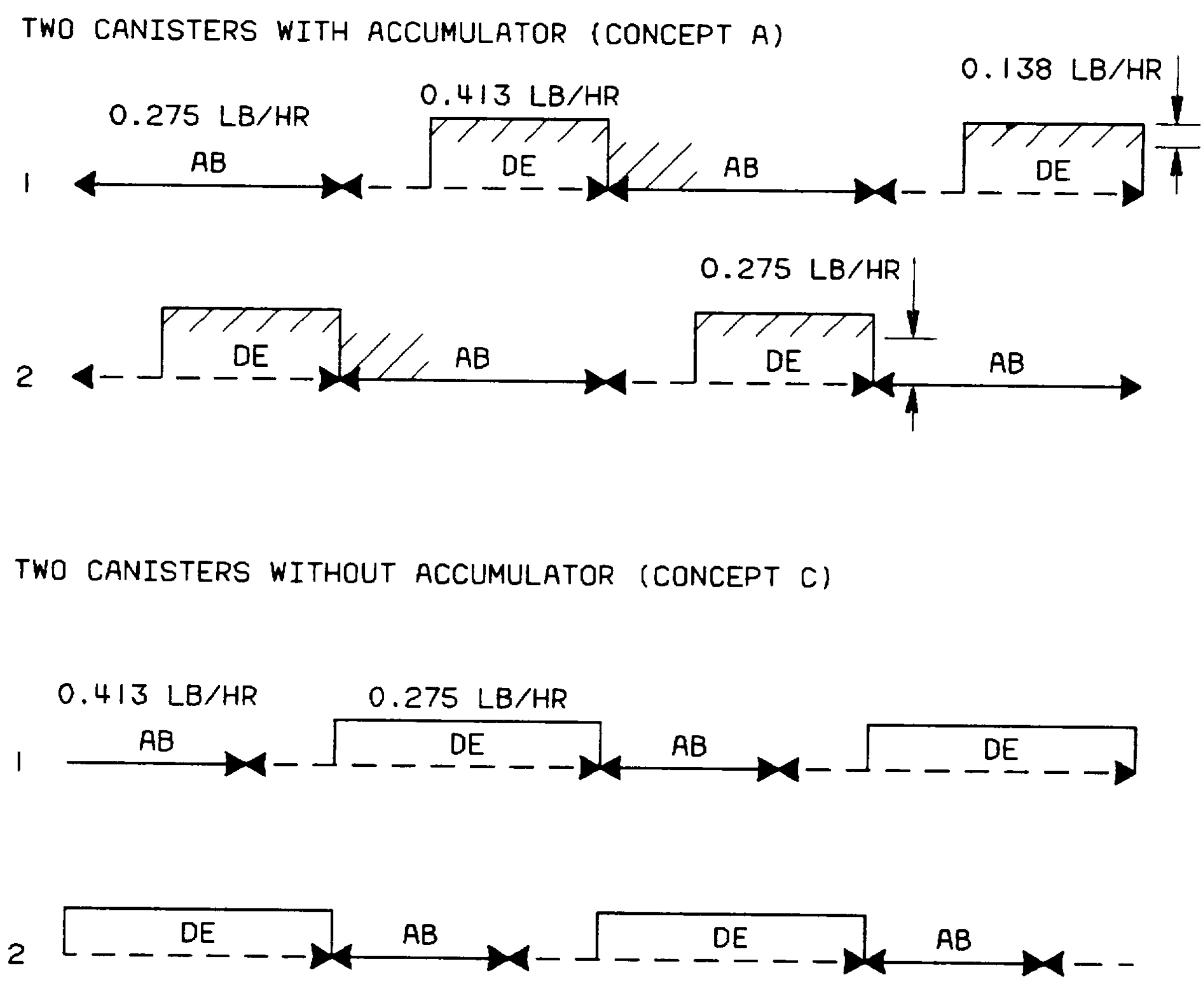


FIGURE 4.1-8
TWO-CANISTER SAWD CONCEPT

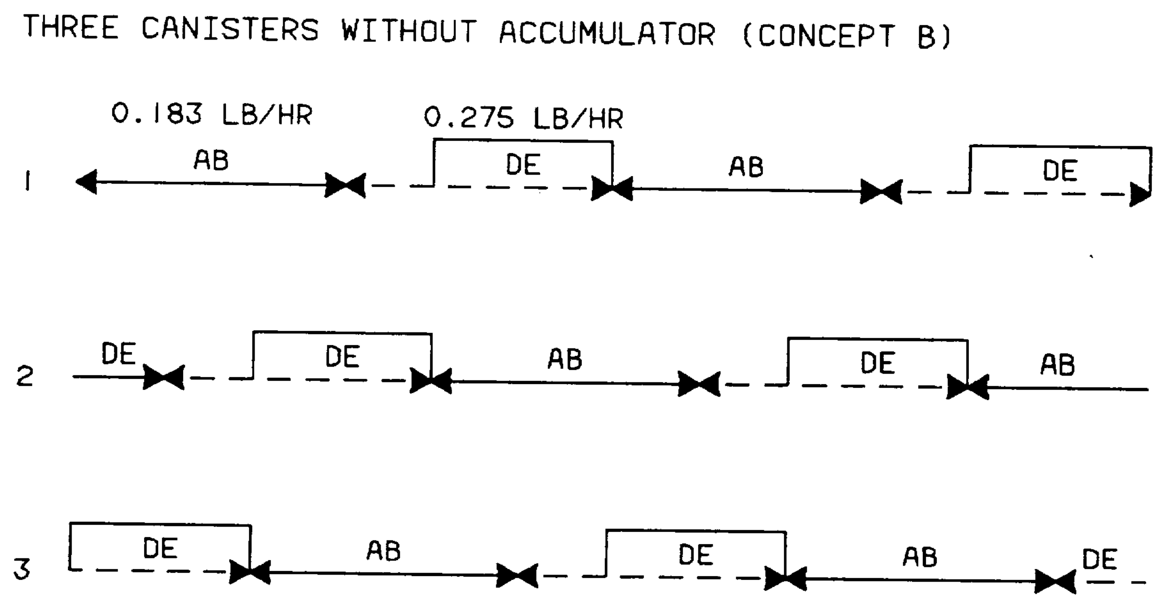


FIGURE 4.1-9
THREE-CANISTER SAWD CONCEPT

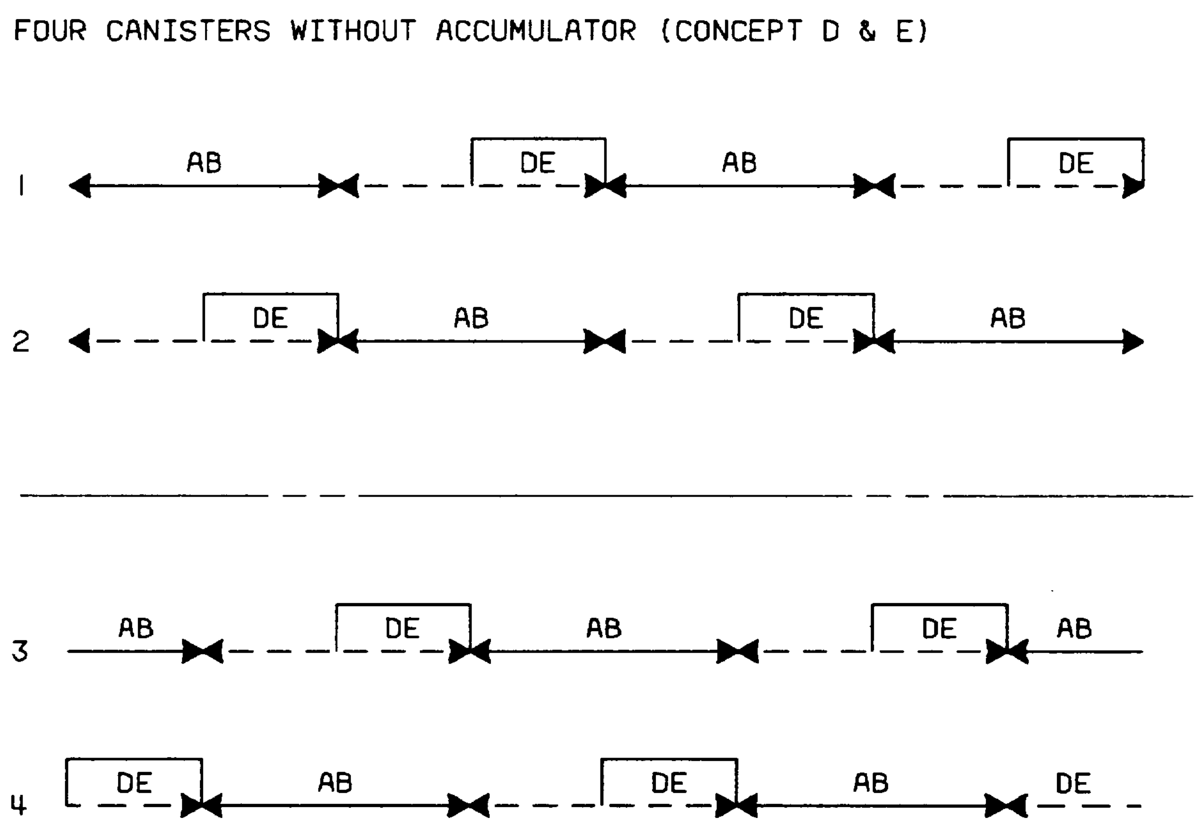


FIGURE 4.1-10
FOUR-CANISTER SAWD CONCEPT

4.2 Component Design

This section describes the significant design considerations related to the subsystem, identifies the components that comprise the subsystem and discusses the operating characteristics of each component. The components break down into three categories; "flight" design, subsystem unique and "off-the-shelf".

The component designs were based on the preliminary specification given in Table 1.0-1 which resulted from the system analysis of section 4.1.

4.2.1 Flight Hardware

Three components, the amine canister, canister isolation valves and steam generator were judged to be critical to demonstrating that a solid amine steam desorb subsystem would work in zero-gravity. Therefore, the design of these three components is representative of actual flight hardware.

4.2.1.1 Canister Isolation Valves

Each canister has one inlet and one outlet valve. The four isolation valves are identical. Each canister isolation valve is a 1.25", 3-way ball valve which is electrically actuated by a 115 VAC, 400 Hz motor. An exploded view of the valve is presented in Figure 4.2-1. The electric actuator incorporates a local valve position indicator, located on top of the actuator, which indicates if the canister is in an absorption, desorption, or energy transfer phase. The phase is then displayed on the DCC. The actuator is thermally isolated from the valve body by a glass reinforced epoxy separator.

The valve body, made of titanium, houses a titanium ball resting on graphite-filled teflon pads on titanium seat retainers (Figure 4.2-2). Sealing is accomplished with spring energized pure teflon "c" seals. During the testing the valve seals were altered by incorporating an additional .047 diameter stainless steel wire within the seal spring and filling the teflon

4.2.1.1 Canister Isolation Valves (Continued)

with a high temperature thermoplastic. Both changes were made to control diametrical growth of the seal which resulted in loss of sealing capability. The titanium metal allows for high strength while providing low weight and low thermal mass. The valve body also contains two ports; one for air and the other for steam. The titanium ball has a total of three ports; two of which are at 90° to each other which align to the common port (canister) and either the air duct or steam duct protruding from the valve body. The steam duct is used for steaming the bed, CO_2 removal to storage, or for energy transfer. The third port is a small bleed port which allows bleeding of steam pressure out of the recently desorbed canister when directed by the controller. All four valves have this port, however, it is only used on the two inlet valves.

4.2.1.2 Amine Canisters

The heart of the SAWD system is the zero-gravity amine canister. The canister houses the IR45 amine bed (later replaced with WA21) which removes the CO_2 from the process air stream. Since the solid amine is desorbed by heating the bed with steam, the moisture content of the amine varies throughout the absorption and desorption cycles. Because amine volume varies directly with moisture content, the canister design must accommodate continual expansion and contraction of the bed. The canister is formed by two bellows and two inverted domes as depicted in Figure 4.2-3. One of the bellows contains the amine and the other forms the canister inlet header. The bellow containing the amine expands as the moisture content increases and contracts as the moisture content decreases. The inlet header bellow contracts as the moisture level increases and expands as it decreases. The spring rates of both bellows act together to maintain a load on the bed and thus prevent bed fluidization. Utilizing inverted domes at each end of the canister minimizes the ullage volume. This will reduce the mixing of CO_2 and ullage air and will provide a high purity of CO_2. An actual amine canister is pictured on Figure 4.2-4.

4.2.1.3 Steam Generator

The steam generator is designed to heat the incoming water to super-heated steam in a zero-gravity environment before entering the solid amine bed. The steam generator which is depicted in Figure 4.2-5, consists of a serpentine stainless steel tube, thermally insulated in a sheet metal enclosure. The tube consists of an inconel sheathed heating element fixed within a stainless steel tube. The small gap between the heater sheath and the stainless steel tube allows the water to flow angularly thus keeping the water close to the heating element for zero-gravity operation. Water is pumped into the steam generator through the inlet fitting and traverses through the tube while being heated by the heating element. The super-heated steam and heating element temperatures are sensed at the steam outlet by two resistance temperature probes. These probes relay the information back to the steam generator control software. The super-heated steam then passes through the outlet and proceeds to the amine bed. (Note that a temperature switch is also located at the steam outlet to provide over temperature protection should the controller fail.)

4.2.2 Unique Hardware

Three components, the CO_2 accumulator, controller and load interface box (driver box) were judged to be unique to the subsystem (i.e., not commercially obtainable) but were not required to be of flight quality to demonstrate zero-gravity operation.

4.2.2.1 CO_2 Accumulator

The CO_2 Storage/Delivery Package, also referred to as the Accumulator, is separate from the rest of the subsystem. The accumulator which is shown in Figure 4.2-6 is a cylindrical stainless steel vessel with convex ends and two mounts welded to its length to serve as legs. There are two plugs as shown in Figure 4.2-7. One is located at the center of one of the ends (the front).

4.2.2.1 CO_2 Accumulator (Continued)

This plug connects with a flexible supply line originating from the CO_2 Removal Package. The second plug is located to the rear of the accumulator along the underside of the length. This plug is used to drain condensate from the accumulator.

The accumulator was designed to be operated at 30 psi and have 2.6 cubic feet of working volume.

4.2.2.2 Controller

The controller provides automatic sequencing and control of the cyclic absorb/desorb process. The controller monitors all operating parameters, actuates the components, calculates subsystem performance data, and provides automatic shutdown in the event of an operational anomaly or the completion of the test series. A list of the various anomalies which the controller guards against is provided in Table 4.2-1.

A modular design approach is used for the process controller, which compliments the software architecture. The core of the process controller is a CMOS microprocessor (NSC 800) which was selected because of its low power dissipation and high noise immunity. This microprocessor has also been flight qualified. The controller memory is built upon 4K by 8 bit erasable programmable read only memory (EPROM) chips, which can be programmed as the software is developed and modified.

As shown in Figure 4.2-8, a data link circuit will be used to send information to the DCC data bus which is a 1553-type data bus and an RS 232 data bus will be used to send information to a TRS 80 or other facility data storage. In addition to the core section of the controller, there is a subsystem dependent

4.2.2.2 Controller (Continued)

section which provides the interfacing to the load interface box. This section contains all the I/O hardware that is necessary to operate the SAWD and to read sensor information.

The process controller is physically mounted directly to the load interface box thereby improving the packaging density. Primary 115 VAC, 60 Hz single phase power is routed directly to the power supply in the load interface box avoiding penetration into the process control housing. This provides for efficient power routing, reduction in EMI coupling, minimizing volume and weight, and maintaining easy access to critical electronics. The process controller electronics consumes approximately 5 Watts from the AC power bus.

Software Description: The process controller contains a modular software package developed by Hamilton Standard for process control. The primary goal of this concept is to reduce software costs by providing techniques which can be easily understood, debugged, and tested. To achieve these goals, Hamilton Standard has developed a generic adaptive software programming method. This concept minimizes the communication problem in translating the user's subsystem requirements into operating software code and provides an easy method for finding problems or understanding subsystem operation. This software is based on a data base structure where the hardware and program processes are in easy to read tabular form. The tables define the states of the variables and the required outputs. The resulting program consists of a System Independent Software (SIS) section and a System Dependent Software (SDS).

The SIS section is written in the "C" language which has a high degree of portability from microprocessor to microprocessor. The SDS can be coded in any other language without restriction to the "C" language. This structure for the software is reflected into the hardware where the core part of the process controller contains the SIS and the dependent section has the SDS.

4.2.2.2 Controller (Continued)

Board #	Description
1	Central Processing Unit (CPU)
2	16K-32K PROM (SIS)
3	16K Non-Volatile RAM
4	Test/Data Communications
5	Miscellaneous-Interrupt Priority, Bite & Wait
6	Dual 1553 Data Bus Interface
7	--Spare--
8	16K-32K PROM (SDS)
9	Discrete 24 Inputs
10	Discrete 24 Outputs
11	Digital/Analog 2 Channel Isolated (8-Bit)
12	Analog/Digital Inputs - 16 Channel Differential (12-Bit)
13	Analog/Digital Outputs - 16 Channel Differential (12-Bit)

4.2.2.3 Load Interface Box (Driver Box)

The load interface box shown in Figures 4.2-9 and 4.2-10 is composed of commercial grade "off-the-shelf" components and contains the power supply for the process controller, signal conditioning for switch and sensor inputs, and drive circuits for loads. The load interface box is the primary link to the components of the subsystem for operation. The devices are listed in the following tabulation:

Item #	Component	Manufacturer/Part #
501	Water Pump Control	IVEK
502	Sensor Conditioning BRD	Hamilton Standard Division UTC
503	Power Supply 5 VDC & $\pm$ 12 VDC	AC DC Electronics
504	Power Supply $\pm$ 12 VDC	Analog Devices

4.2.2.3 Interface Load Box (Driver Box) (Continued)

Item #	Component	Manufacturer's Part #
505-512	Relays	602-1 Teledyne
513	Blower Control	Rotron
514	Relay	ODC5
515-520	Relays	OAC5
521, 522	Relays	1AC5
523	Relay	1DC5
524	Relay	OAC5
525	Flow Meter Signal Conditioning	TSI, Inc. (DELETED)
526	KCA-DEK Relay	LEACH
527	Relay	652-1 Teledyne
528-530	JCA-J2K Relays	LEACH

4.2.3 "Off-The-Shelf" Hardware

The "off-the-shelf" components fall into three categories. Non-electrical components which contribute to the control of the process but which are not controlled by the subsystem controller; instrumentation which supplies information to the subsystem controller; and electrical activated controls which contribute to process control and are controlled by the subsystem controller.

4.2.3.1 Non-Electrical Controls

These devices are listed below;

Item #	101	102	103	104	105
Component	Relief Valve	Check Valve	Back Pressure Regulator	Pressure Regulator	Metering Valve
Drawing #	SVSK108567	SVSK108566	SVSK109169	SVSK109169	SVSK109169
Manufacturer	Circle Seal Controls	Circle Seal Controls	Fairchild Industrial Products	Fairchild Industrial Products	Whitney
Mfg Part #	D562T-4D-16.3	862T-4BB	10132BPT	10122TL	SS-2M64
Cracking Pressure	25 ± 0.2 psig	8 IWG			
Burst Pressure		1500 psig			1000 psig
Operating Pressure		0-600 psig	30 ± 0.2 psig	100 ± 0.1 psi supply 20 psi set	18.3 psia
Operating Temp.		-65F to 180F	-40F to 200F	-40F to 200F	-10F to 400F

4.2.3.1 Non-Electrical Controls (Continued)

Item #	101	102	103	104	105
Sensitivity			1/8 in. W.C.	1/8 in. W.C.	
Flow Capacity			40 scfm	40 scfm (supply) 25 psi	0.275 pph
Exhaust Capacity				5.5 scfm	

4.2.3.2 Instrumentation

These devices are listed in the following tabulation:

Item #	301 to 306	307	308	309
Component	Resistance Thermometers	Pressure Switch	Flow (ΔP) Transducer	Pressure Transducer
Drawing #	SVSK108597	SVSK109169		SVSK109169
Manufacturer	OMEGA Engr. PR-13-2-100	Precision Sensors	OMEGA	OMEGA Engr.
Mfg. Part #	1/8-5 1/2-A	PIOM-87	PX162027G	PX100-0306V
Resistance	100 @ 0^oC			

4.2.3.2 Instrumentation (Continued)

Item #	301 to 306	307	308	309
Length	5.5 in.			
Sheath Diameter	0.125 in.			
Operating Press.		10 ± 5 psig	0 to 5 psi	0 to 30 psig
Flow Rate			0 to 0.065 scfm	

4.2.3.3 Electronically Activated Controls

These devices are listed in Table 4.2-2:

TABLE 4.2-1

LIST OF AUTOMATIC SHUTDOWNS

PRIORITY	SEVERITY	ITEM #	ITEM NAME	ANOMALY
1	ALARM	410	WATER PUMP	ROTATION > 220 RPM DETECTED WHEN WATER PUMP IS OFF
2	ALARM	411	STEAM GENERATOR	HIGH TEMPERATURE > 400 F WHEN STEAM GENERATOR IS OFF
3	ALARM	412	PROCESS AIR BLOWER	FAN ROTATION > 2400 RPM DETECTED WHEN FAN IS OFF
4	ALARM	411	STEAM GENERATOR	WARM-UP: HIGH TEMPERATURE > 400 F AFTER 40 MINUTES
5	ALARM	411	STEAM GENERATOR	PRE-HEAT: HIGH TEMPERATURE > 400 F
6	ALARM	411	STEAM GENERATOR	PROCESS OR ENERGY TRANSFER: HIGH TEMPERATURE > 400 F AFTER 10 MINUTES IN EACH CYCLE
7	ALARM	410	WATER PUMP	WARM-UP OR PROCESS: HIGH DISCHARGE PRESSURE> 100 PSIG
8	ALARM	401/402	INLET/OUTLET VALVE	OUT OF POSITION WHEN < 80% WHILE ABSORB BED 1
9	ALARM	403/404	INLET/OUTLET VALVE	OUT OF POSITION WHEN < 80% WHILE ABSORB BED 2
10	ALARM	401/402	INLET/OUTLET VALVE	OUT OF POSITION WHEN > 35% WHILE DESORB BED 1
11	ALARM	403/404	INLET/OUTLET VALVE	OUT OF POSITION WHEN > 35% WHILE DESORB BED 2
12	ALARM	405	ENERGY TRANSFER VALVE	VALVE CLOSED WHEN NOT IN ENERGY TRANSFER PHASE
13	ALARM	405	ENERGY TRANSFER VALVE	VALVE CLOSED WHEN IN ENERGY TRANSFER PHASE
14	ALARM	410	WATER PUMP	HIGH SPEED > 700 RPM
15	ALARM	308	ULLAGE FLOW SENSOR	PROCESS; < 0.0 OR > 0.08 WHILE 406 —> CABIN
16	ALARM	201/202	INLET BED 1/BED 2	WARM-UP OR PROCESS: HIGH INLET TEMPERATURE >300 F ON DESORBING BED
17	ALARM	201/202	INLET BED 1/BED 2	PROCESS: HIGH INLET TEMPERATURE > 100 F AFTER 25 MINUTES ON ABSORBING BED
18	ALARM	203	ACCUMULATOR	PROCESS: HIGH C02 PRESSURE > 33 PSIA
19	ALARM	411	STEAM GENERATOR	PROCESS OR ENERGY TRANSFER: LOW TEMPERATURE < 230 F FOR 10 MINUTES
20	ALARM	411	STEAM GENERATOR	WARM-UP: LOW TEMPERATURE < 230 F FOR 10 MINUTES
21	ALARM	201/202	INLET BED 1/BED 2	WARM-UP AND PROCESS: LOW INLET TEMPERATURE < 200 F AFTER 25 MINUTES
22	ALARM	201/202	BED 1/BED 2	PROCESS: DESORPTION PERIOD TOO LONG > 150 MINUTES
23	ALARM	201/202	BED 1/BED 2	WARM-UP: DESORPTION PERIOD TOO LONG > 120 MINUTES
24	ALARM	308	ULLAGE FLOW SENSOR	PROCESS: EXCESS ULLAGE FLOW TO CABIN > 0.0275 AFTER 5 MINUTES WHILE 406 —> ACCUMULATOR
25	ALARM	406	DESORP. DIVERTER VALVE	FLOW TO ACCUMULATOR TOO EARLY IN DESORB CYCLE (406 —> ACCUM. <10 MIN. IN DESORB)
26	ALARM	201/202	BED 1/BED 2	WARM-UP OR PROCESS: DESORPTION PERIOD TOO SHORT > 180 F BEFORE 20 MINUTES
27	ALARM	412	PROCESS AIR BLOWER	PROCESS OF ENERGY TRANSFER: FAN SPEED OUT OF RANGE < 1200 RPM OR > 6200 RPM
28	ALARM	411	STEAM GENERATOR	PRE-HEAT: TOO LONG < 280 F AFTER 5 MINUTES
29	WARNING	—	————	CALCULATED ABSORB TIME TOO SHORT OR TOO LONG
30	WARNING	202	INLET BED 2	ENERGY TRANSFER BED 1 TO BED 2: LOW TEMPERATURE < 130 F AFTER 2.5 MINUTES
31	WARNING	201	INLET BED 1	ENERGY TRANSFER BED 2 TO BED 1: LOW TEMPERATURE < 130 F AFTER 2.5 MINUTES
32	WARNING	203	ACCUMULATOR	PROCESS: C02 PRESSURE OUT OF RANGE < 23.5 PSIA OR > 30.0 PSIA

NOTE: THIS WAS DROPPED WHEN SUBSYSTEM REVISED

TABLE 4.2-2
ELECTRICALLY ACTIVATED DEVICES

Item #	401-404	405 (DELETED)	406	407	408	409	410	411	412
Component	Inlet Outlet Valves	Energy Transfer Valve	Desorption Diverter Valve	CO_2 Overboard Valve	CO_2 Reduction Valve	Water Supply Valve	Water Pump	Steam Generator	Process Air Blower
Drawing #	SVSK 109168 Rev. A	SVSK 109167	SVSK 108604	SVSK 108602	SVSK 108602	SVSK 108602	SVSK 108612	SVSK 108594	SVSK 108586
Manufacturer	Hamilton Std. UTC	VALCOR Engr.	Skinner	Skinner	Skinner	Skinner	IVEK	Hamilton STD UTC	ROTRON
Mfg Part #	SVSK-109168-1	V70200 -14	B16-RX-4	B2-RX-46	B2-RX-46	B2-RX-46	660-B		SPL1474
Volt	115 @ 400 Hz	26-30 VDC	120 VAC @ 60 Hz	120 VAC @ 60 Hz	120 VAC @ 60 Hz	120 VAC @ 60 Hz	120 VAC @60Hz	120 VAC @ 60Hz	28 VDC
Position	3-way 3 position	2-way 2 position	3-way 3 position	2-way 2 position	2-way 2 position	2-way 2 position			
Flow Capacity							0-13.2 pph H_2O	3.54 pph	6-25 scfm
Discharge							200 psig		16.6 in H_2O
Speed Range							0-660 RPM		
Power								1.0 KW	

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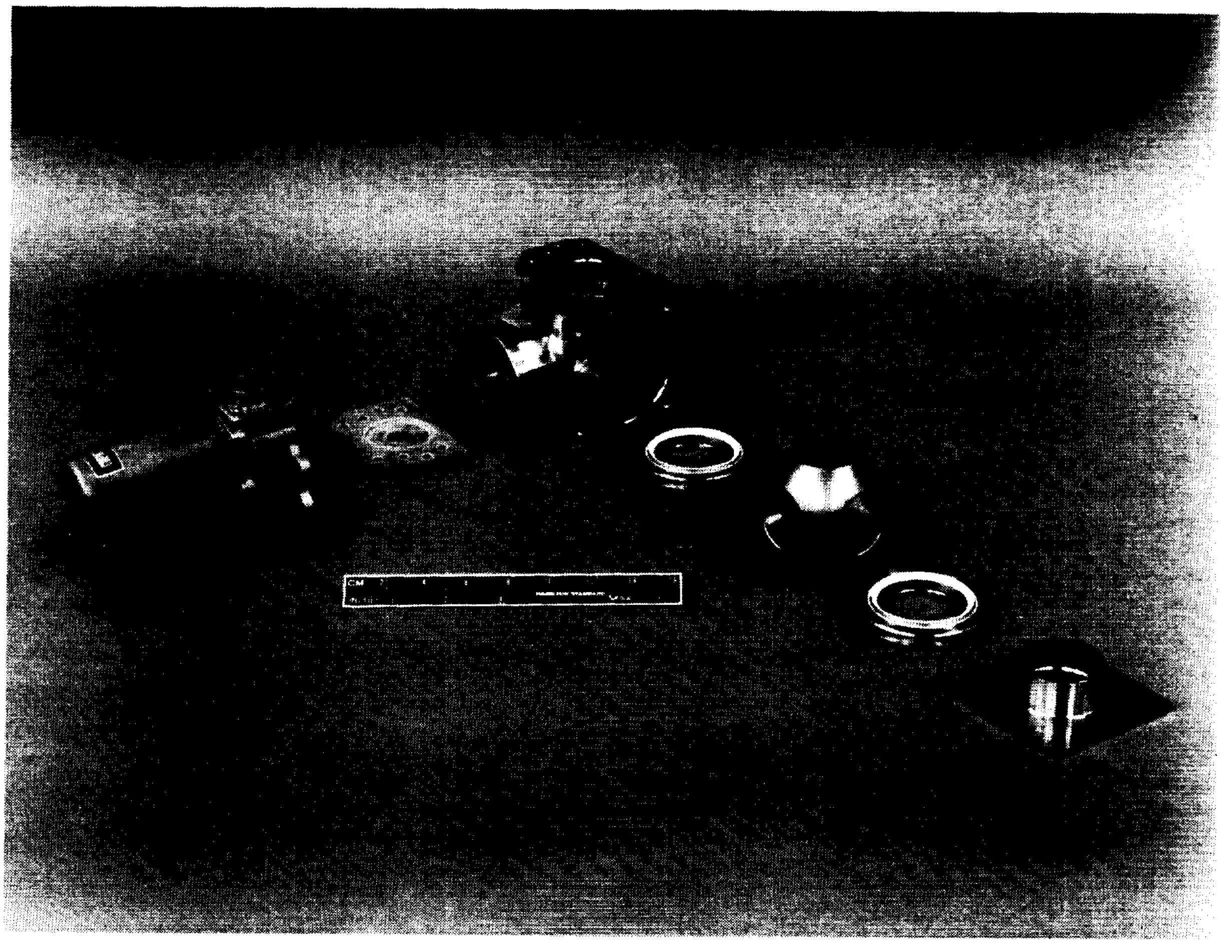
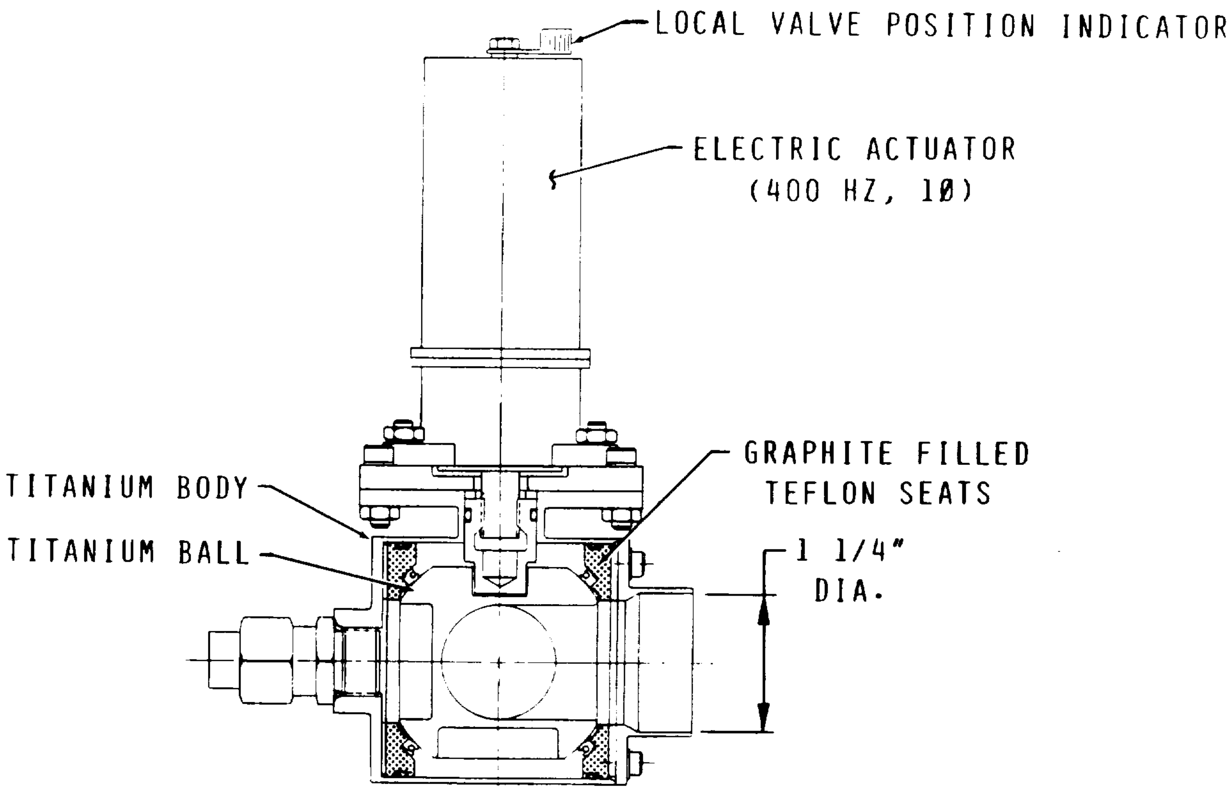


FIGURE 4.2-1
SAWD II CANISTER VALVE



- INTEGRAL PLATINUM PROBE PORT
- FEEDBACK POTENTIOMETER FOR POSITION INDICATION

FIGURE 4.2-2
SAWD II CANISTER VALVE

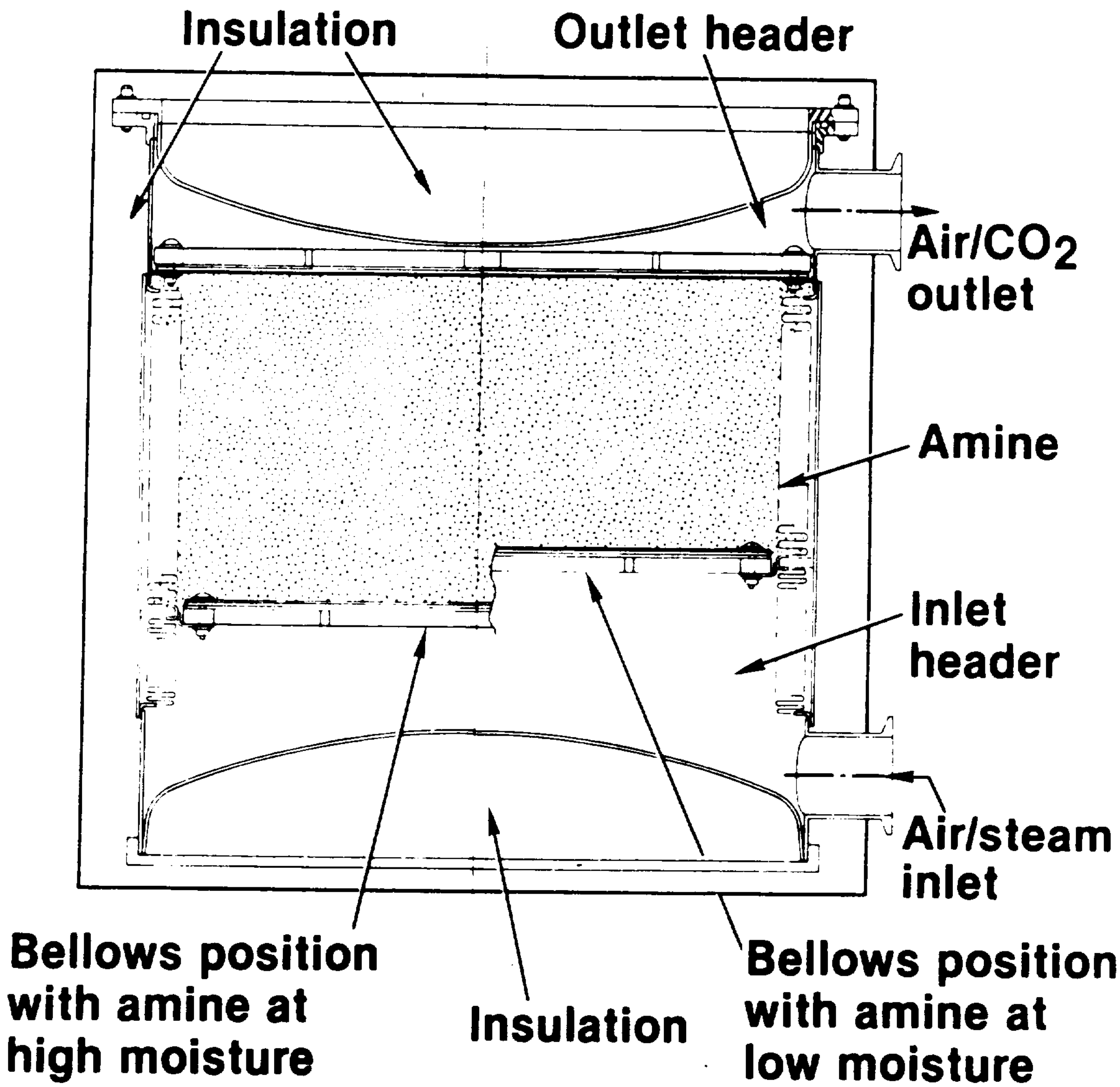


FIGURE 4.2-3
SAWD II ZERO-GRAVITY AMINE CANISTER DIAGRAM

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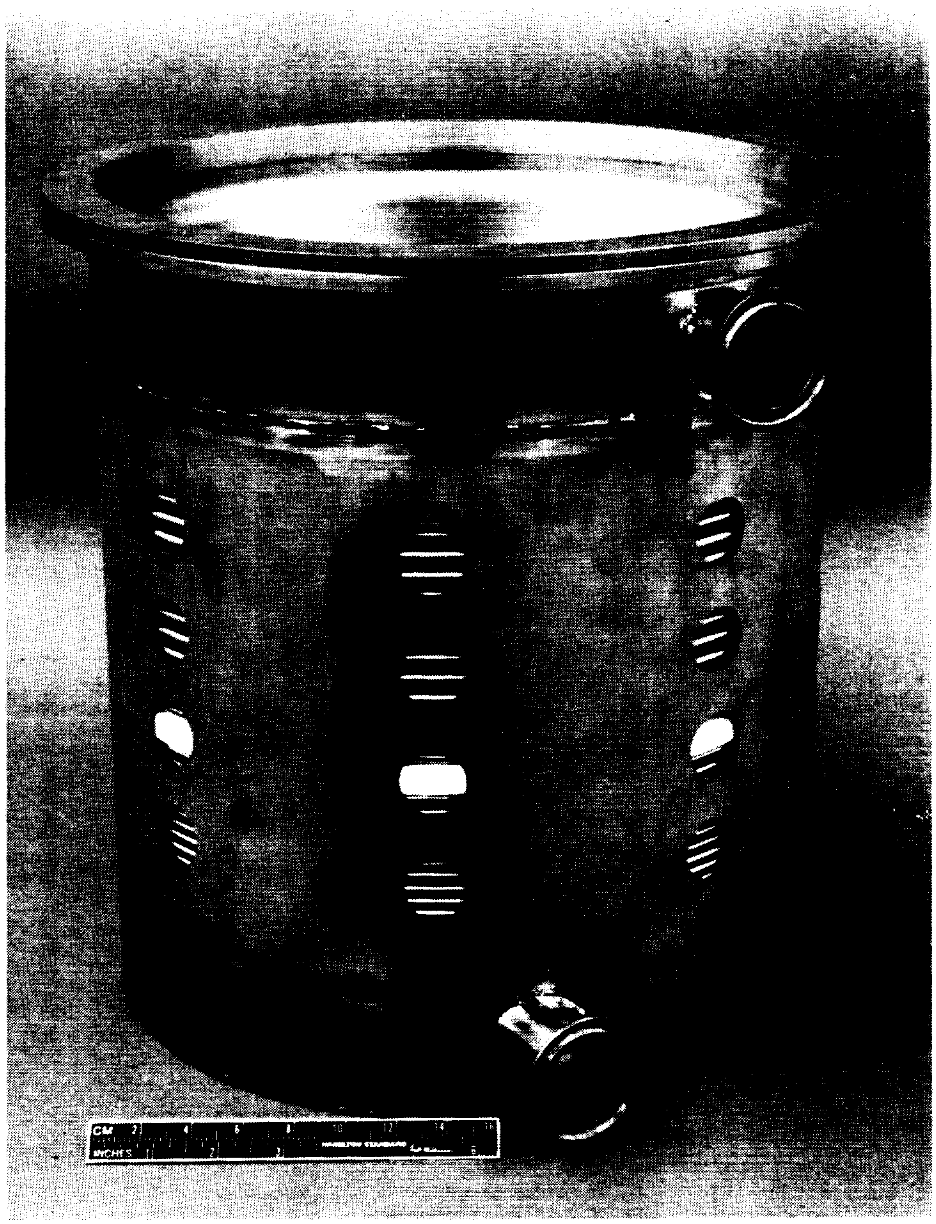
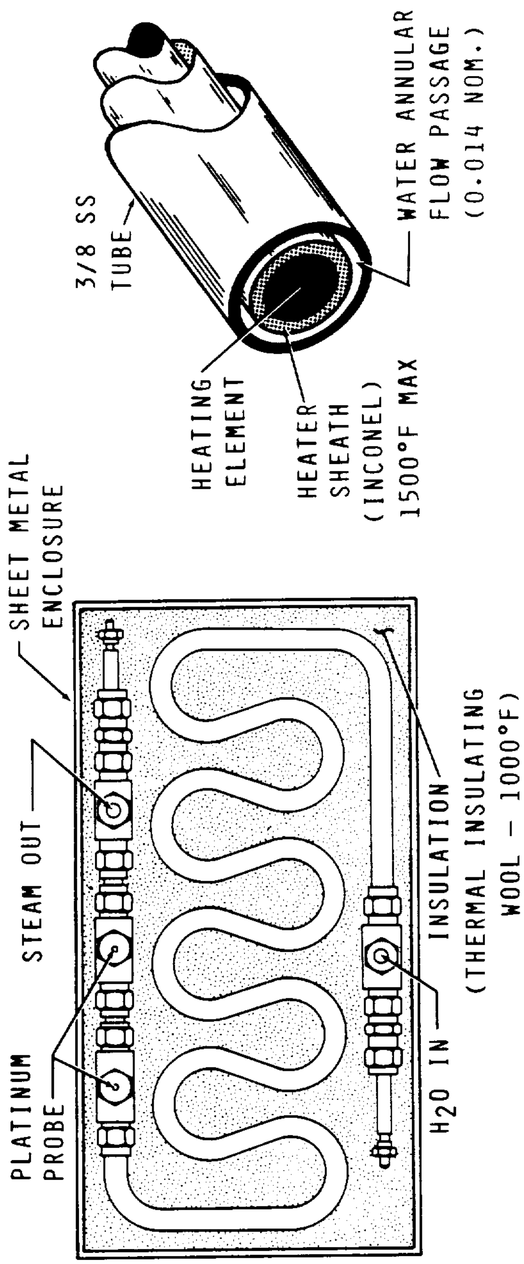


FIGURE 4.2-4
SAWD II ZERO-GRAVITY AMINE CANISTER



- PLATINUM PROBES FOR CONTROL & SHUTDOWN
- VARIABLE HEATER POWER (200 - 1000 WATTS)
- MODULATION POWER VARIATION VIA PULSE WIDTH
- 110 VAC, 60 Hz, 1Ø

FIGURE 4.2-5

SAWD II STEAM GENERATOR

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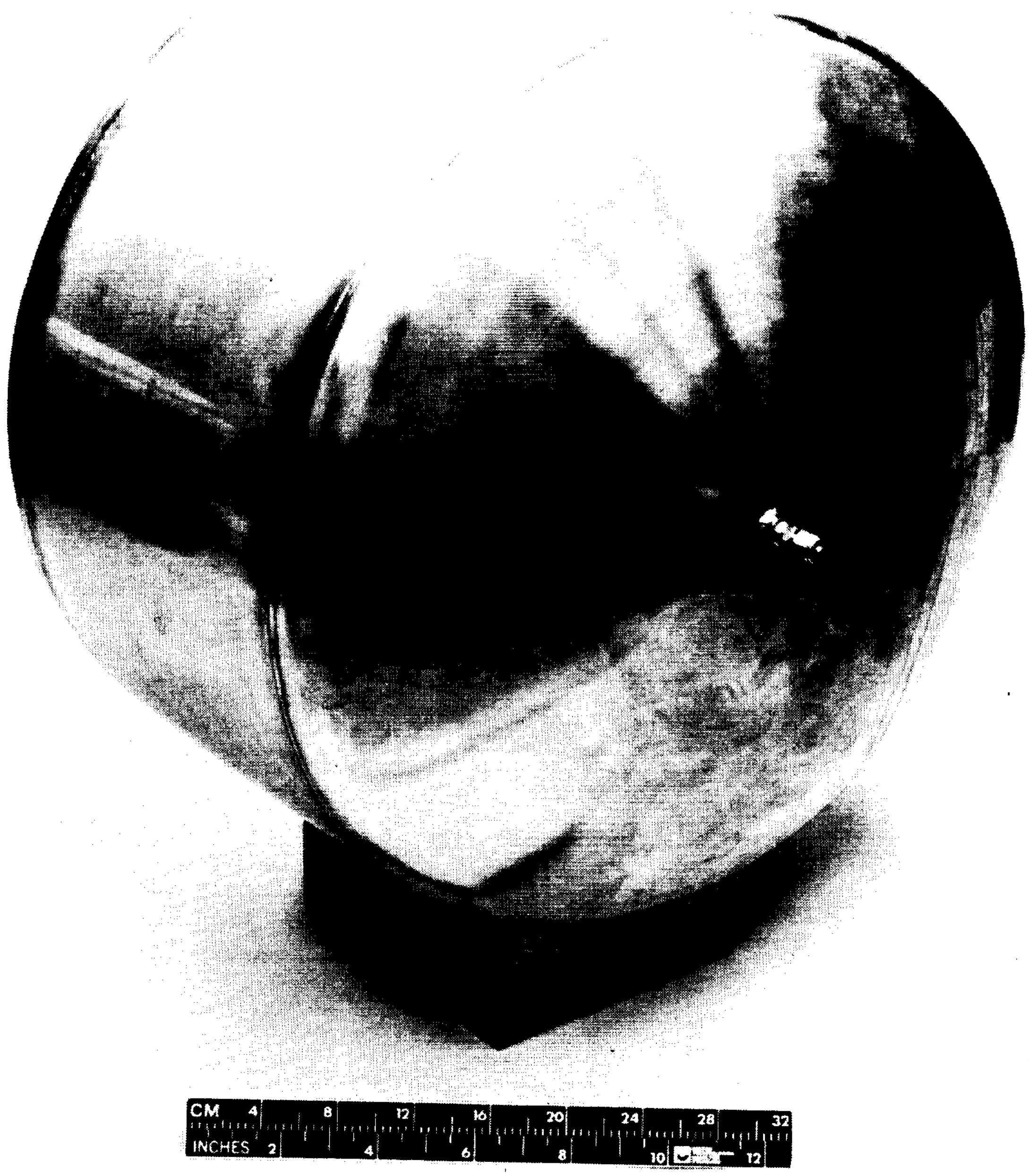

FIGURE 4.2-6
SAWD II ACCUMULATOR

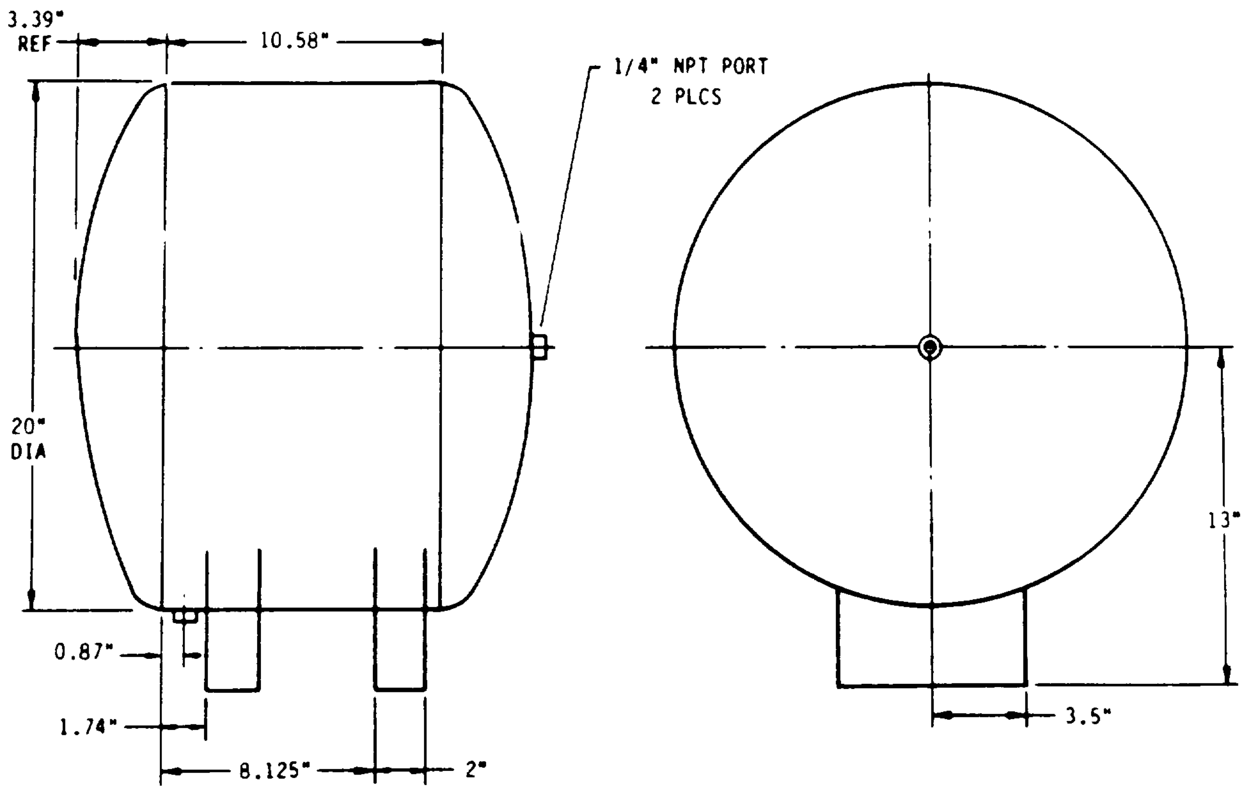

FIGURE 4.2-7

SAWD II ACCUMULATOR DIAGRAM

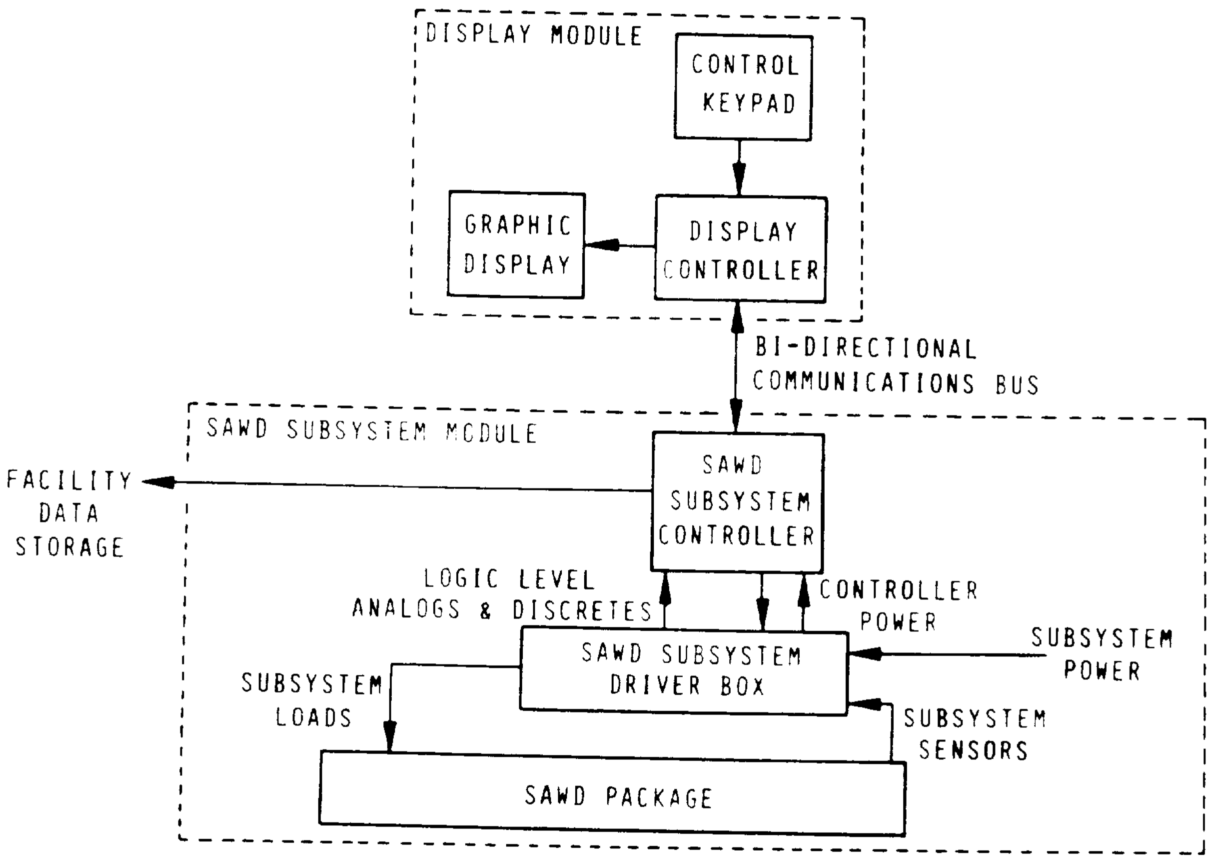

FIGURE 4.2-8
SAWD II CONTROLLER BLOCK DIAGRAM

501 Water Pump Control
502 Sensor Conditioning BRD
503 5 VDC Power Supply
504 12 VDC Power Supply
505 Relay; V2 Absorb
506 Relay; V4 Desorb
507 Relay; V1 Desorb
508 Relay; V4 Absorb
509 Relay; V1 Absorb
510 Relay; V2 Desorb
511 Relay; V3 Desorb
512 Relay; V3 Absorb
513 Blower Control
514 Relay; V5
515 Relay; V6
516 Relay; V7
517 Relay; V8
518 Relay; V9
519 Relay; Water Pump
520 Relay; Blower Control
521 Relay; 60 Hz Feedback Signal
522 Relay; 400 Hz Feedback Signal
523 Relay; 28 VDC Feedback Signal
524 Relay; Emergency Shutdown Control
525 Conditioning Electronics; Flow Meter (DELETED, Replaced with plumbing line heater controller)
526 Relay; Blower Power
527 Relay; Steam Generator
528 Relay; 60 Hz Emergency Shutdown
529 Relay; 400 Hz Emergency Shutdown
530 Relay; 28 VDC Emergency Shutdown

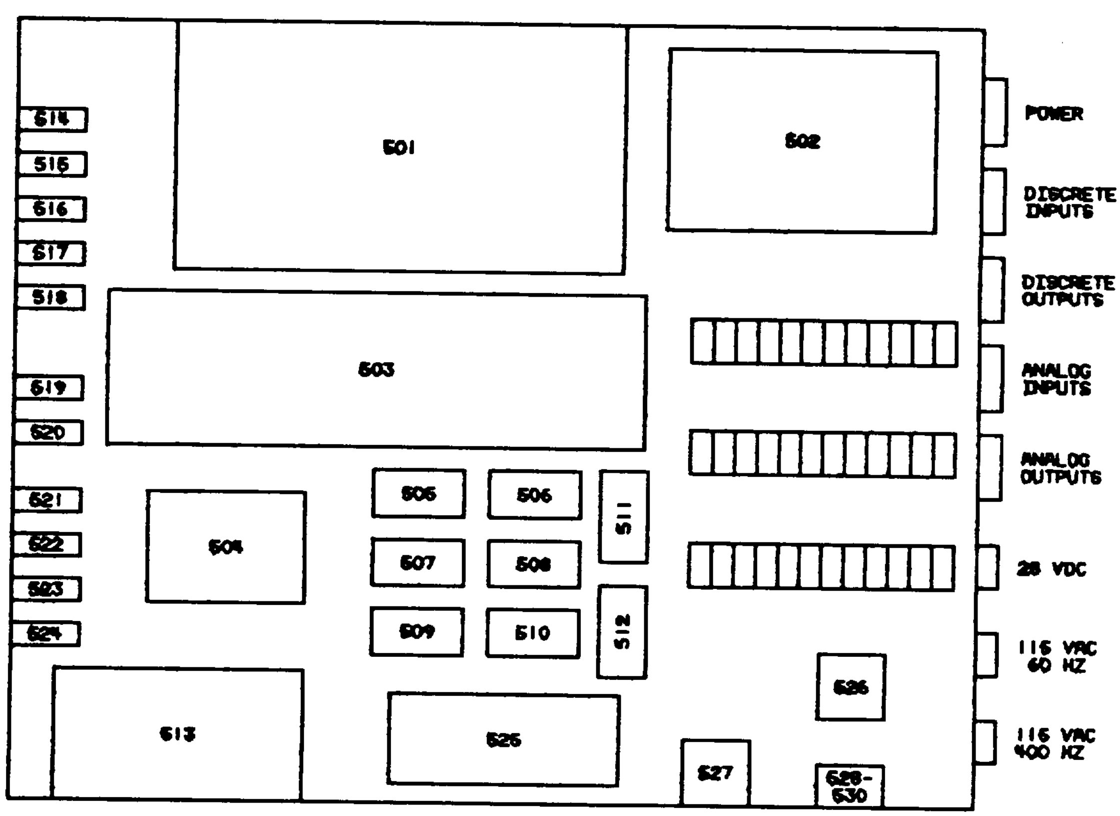

FIGURE 4.2-9
DRIVER BOX LAYOUT

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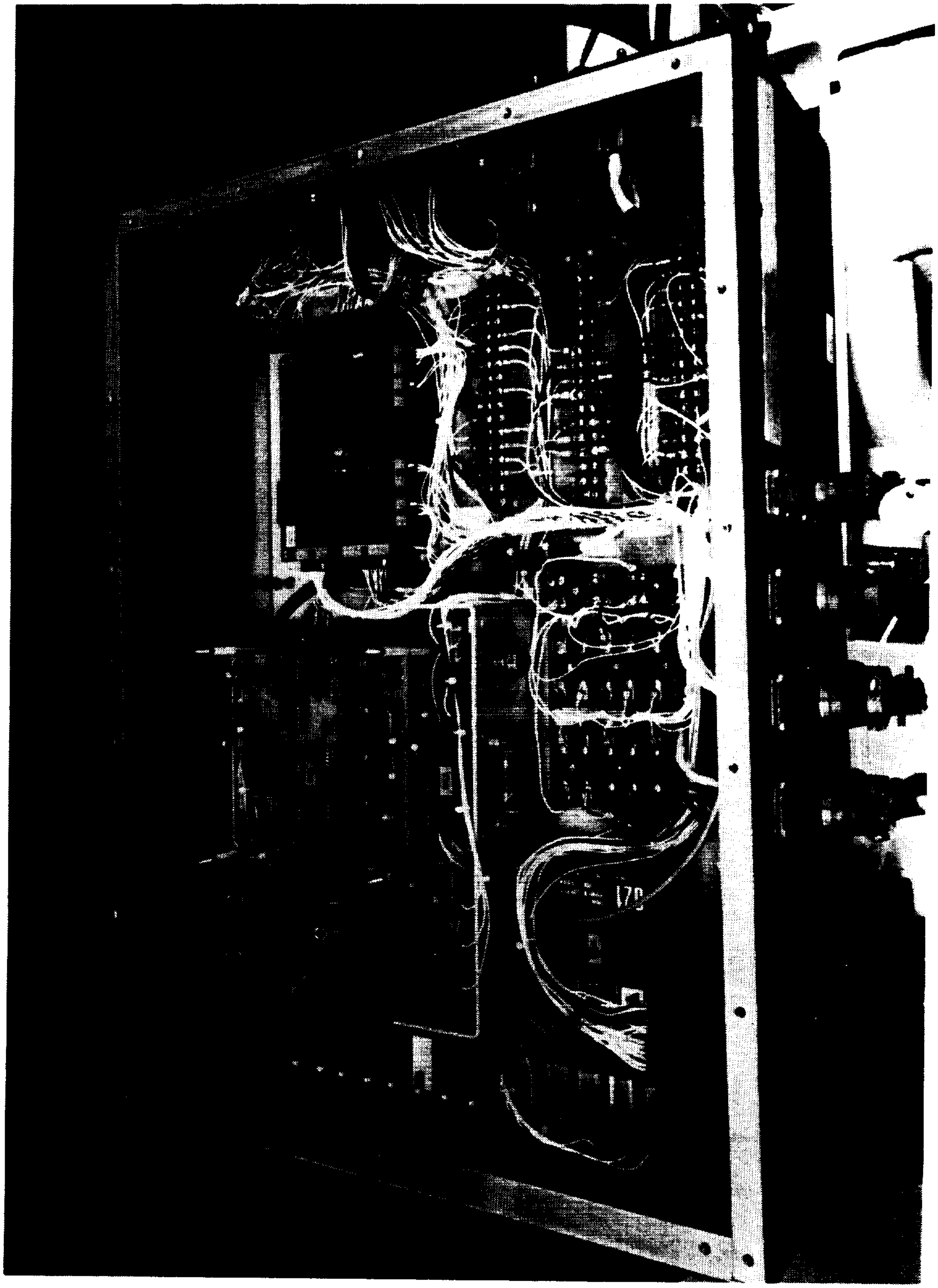

FIGURE 4.2-10
DRIVER BOX

4.3 System Description and Operation

4.3.1 System Description

The SAWD II subsystem which is characterized on Figure 4.3-1 consists of a process package, which houses all major mechanical components; an accumulator, which stores the CO_2; a driver box which houses electrical hardware; and a controller, which monitors and controls subsystem operation.

The process package and control components were previously listed and shown schematically on Figures 1.0-1 and 1.0-5. These components are mounted inside a frame 88.9 x 55.8 x 41.9 cm (35 x 22 x 16.5 in). Mounted to the top of the frame is a 58.5 x 45.7 x 17.8 cm (23 x 18 x 7 in.) driver box containing solid state relays and other drive electronics and the subsystem controller measuring 27.9 x 24.1 x 16.5 cm (11 x 9.5 x 6.5). This brings the overall dimensions of the process package to 88.9 x 55.8 x 60.9 cm (35 x 22 x 24 in.0 with a weight of 87.3 kilograms (192 pounds). Interface connections are located on the right side as shown in Figures 1.0-4 and 1.0-8. The interfaces are described in Table 4.3-1.

The accumulator has an internal volume of 75.7 liters (2.67 ft^3) and is comprised of a 50.8 cm (20 in) diameter section which is 26.7 cm (10.5 in.) in length with 8.90 cm (3.5 in.) domed ends. Two 17.8 cm (7 in.) wide by 5.1 cm (2.0 in.) mounts welded along the edge of the cylinder form the legs and result in an overall height of 58.4 cm (23 in.) (Figure 4.2-6).

Additional component descriptions are available in the Installation/Operation Manual, SVHSER10633.

4.3.2 Subsystem Operation

To simplify the explanation, it is assumed that Bed 1 will be desorbed first. When first powered, the system will be in the off mode and off state. When the on mode is selected, the controller begins the steam generator pre-heat. Upon completion of the steam generator pre-heat, the controller begins

4.3.2 Subsystem Operation (Continued)

desorption of Bed 1. After completing desorption an energy transfer is initiated. During this phase of operation, energy, in the form of steam, is transferred from Bed 1 to Bed 2. At the completion of the energy transfer, normal cyclic operation continues with the absorption of Bed 1 and the simultaneous desorption of Bed 2. This cyclic operation is depicted in Figure 4.3-2.

4.3.2.2 Absorption

In addition to removing CO_2 during absorption, the resin bed also humidifies the air stream. This process eliminates the heat of CO_2 absorption and permits the water, which was added during the previous desorption, to be removed, thereby maintaining a stable bed water loading. Initially the process controller determined the length of absorb time necessary to dry the bed. This was based on water loading and the relative humidity of the air. During the development test this was changed to a constant 53 minutes and the range of inlet air relative humidity was limited. The length of the absorption time is nominally 53 minutes, however if the other bed has not completed its desorption, the absorption is continued at a reduced air flow rate. Figures 4.3-3 and 4.3-4 show the system in the absorb bed #1 configuration. Figure 4.3-5 shows the changes in bed conditions during absorption.

4.3.2.3 Original Design Energy Transfer

An originally desined energy was transferred in the following manner. At the onset of the energy transfer, the inlet valve on Canister 1 is positioned to the bleed port and the inlet valve on Canister 2 remains in the desorption position (Figure 4.3-6). This valve configuration allows the canister pressures to equalize with each other prior to air flow.

This pressure equalization occurs over a one minute time period. The inlet valve on Canister 2 is then placed in the absorb position and the inlet valve

4.3.2.3 Initial Energy Transfer (Continued)

on Canister 1 is placed in the desorb position (Figure 4.3-7). The outlet valves on Canisters 1 and 2 remain in their current position of absorption and desorption, respectively. The energy transfer valve is opened and hot air flows into Canister 1 at a rate of 5 scfm. This is done to raise the temperature of the absorbed bed prior to desorption and to lower the temperature of the desorbed bed, which will reduce the heated air and moisture released to the cabin atmosphere during absorption of that bed. After two minutes, the energy transfer valve is closed and the outlet valves of Canisters 1 and 2 are placed in the desorb and absorb positions, respectively. The normal cyclic operation continues with Canister 1 desorbing and Canister 2 absorbing.

4.3.2.4 Revised Energy Transfer

During the development testing the energy transfer was revised as follows. At the onset of the energy transfer the inlet valve of Bed #1 (absorbing bed) is repositioned to the desorb position. This position allows Bed #2's (desorb bed) steam pressure to bleed down to atmospheric pressure through Bed #1 (Figure 4.3-8). The steam condenses on the inlet portion of Bed #1 and provides part of the energy required for desorption. The ullage air is pushed through the Bed #1 outlet valve and returned to the cabin via the air outlet duct. During the two minute energy transfer the fan which is dead headed is operated at a low speed. At the end of the energy transfer the outlet valve of Bed #1 is switched from absorb to desorb, and the inlet and outlet valves of Bed #2 are switched from desorb to absorb. Normal cyclic operation continues. Bed #2 begins its absorption phase and Bed #1 begins its desorption phase.

4.3.2.5 Desorption (Bed #1)

There is no difference between the initial and the final configuration relative to its desorption. During the first part of desorption, the CO_2 diverter valve (Item 406) is positioned to allow any trapped air to leave the canister

4.3.2.5 Desorption (Bed #1) (Continued)

through the flow sensor (Figure 4.3-9). This stage is considered complete when the CO_2 begins to leave the canister and the resulting increase in flow causes an increase in pressure drop, which is sensed by the flow transducer. After a one minute delay the subsystem controller then repositions the CO_2 diverter valve to direct the flow to the accumulator (Figure 4.3-10).

CO_2 continues to be evolved, however, flow momentarily stops until the pressure in the canister equals that of the accumulator. The accumulator pressure ranges from ambient to 206.8 kPa absolute (30 psia), depending on whether CO_2 is being delivered to overboard or to a reduction system. When the CO_2 is being supplied to a reduction system the pressure in the accumulator ranges from 158.6 to 206.8 kPa (23 to 30 psia).

During desorption a very sharp temperature gradient exists within the bed. At the inlet to the bed, where steam heating has taken place, the bed temperature is equal to the saturated steam temperature for the existing bed pressure. Downstream in the bed, the temperature is approximately equal to the wet bulb temperature which existed during the previous absorption cycle.

During desorption this temperature front propagates through the bed (Figure 4.3-11). At the end of the desorption phase the outlet temperature rapidly rises until it reaches 180^{o}F, at which time the controller shuts off the water pump to stop steam production.

The desorption time is nominally set to complete desorption when the absorption of the other bed is complete. The time is controlled by varying the steam flow rate. The selected steam flow rate is based upon the total steam required to desorb the bed during its last desorption cycle and the desired time. If the present desorption cycle is completed earlier than the absorption cycle, then the desorbed bed remains in a static condition until the absorption of the other bed is completed.

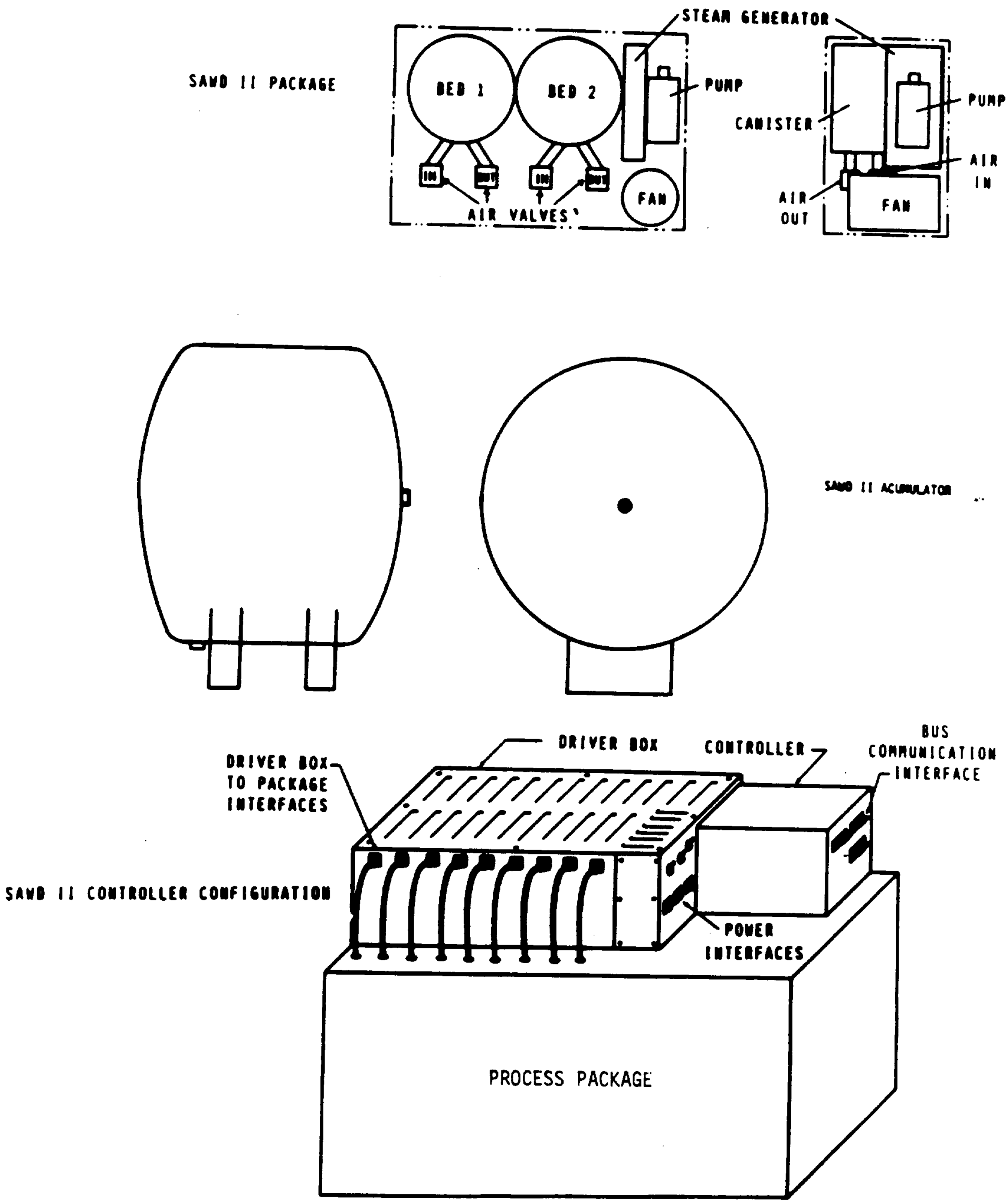

FIGURE 4.3-1
BASIC SAWD II SUBSYSTEM ASSEMBLY

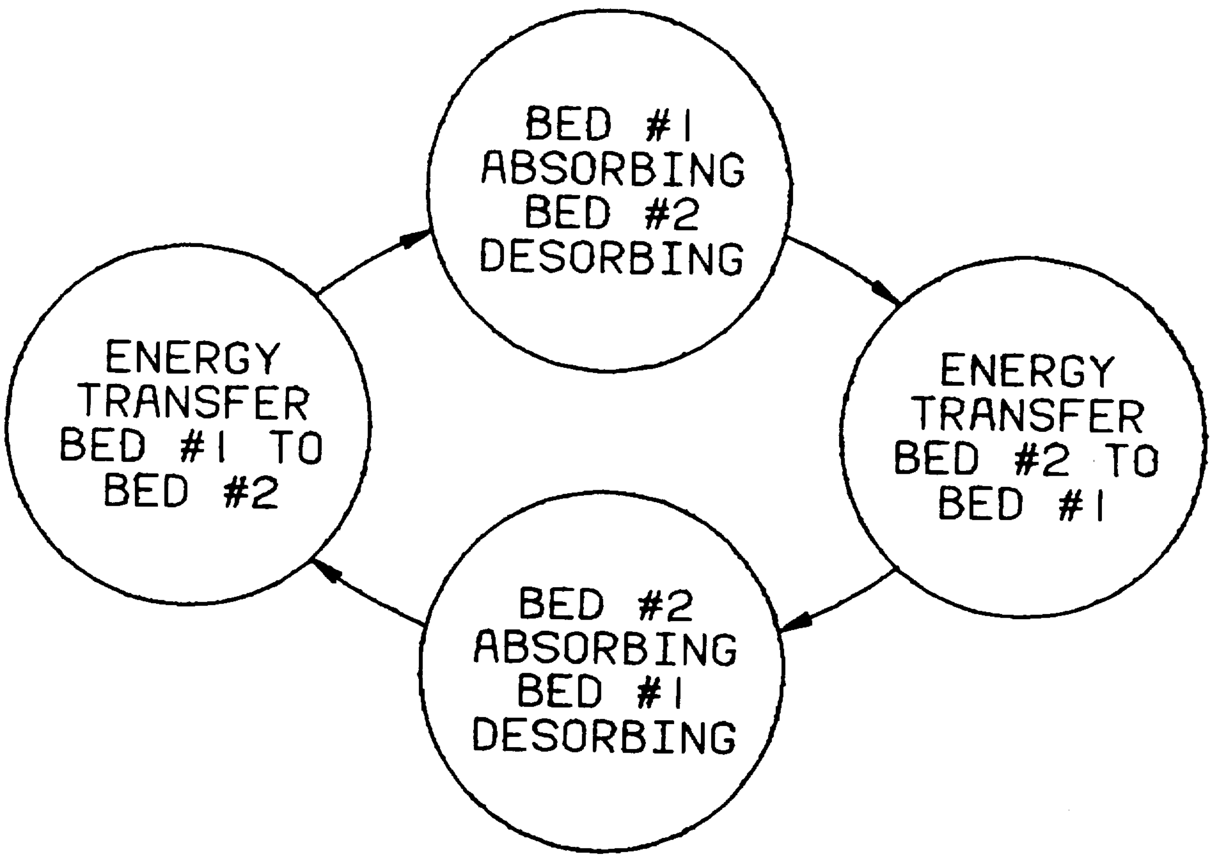

FIGURE 4.3-2
NORMAL CYCLE OPERATION

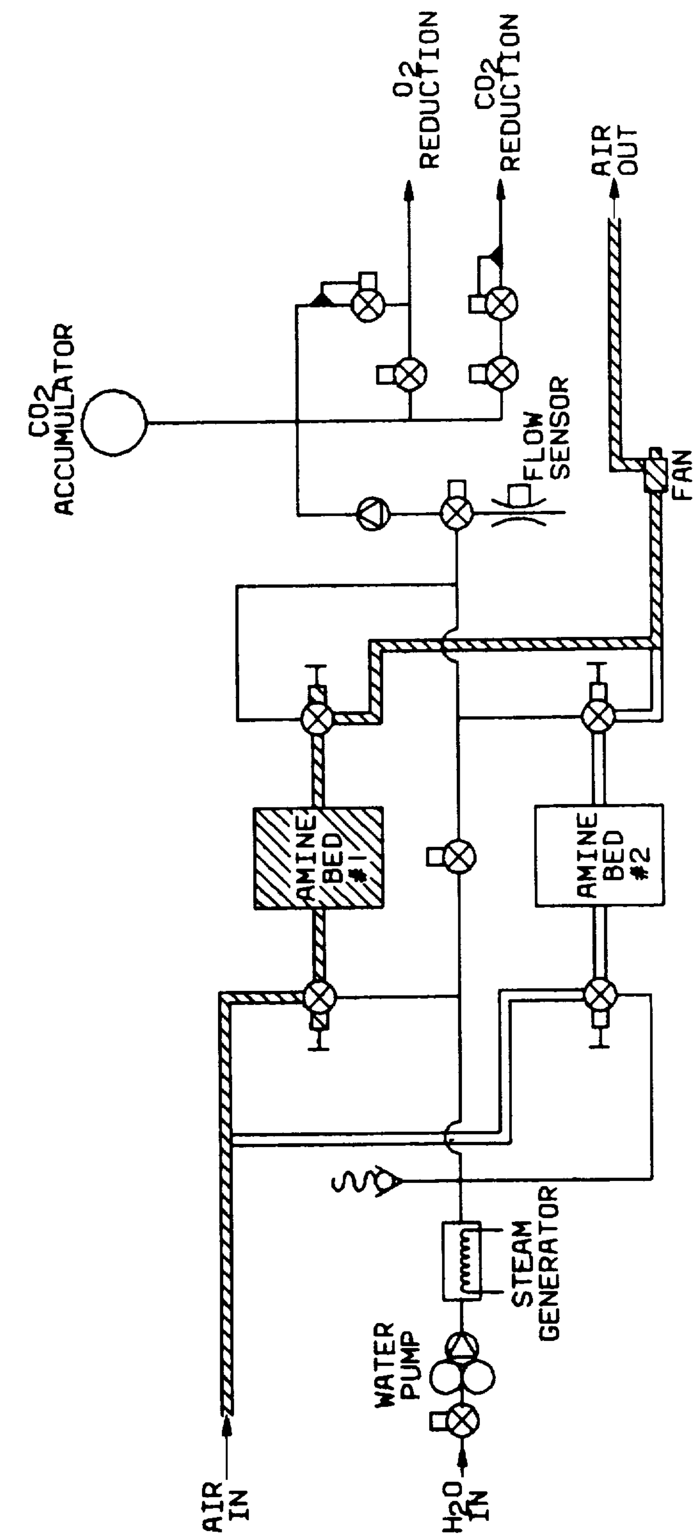

FIGURE 4.3-3

ABSORPTION BED #1 SCHEMATIC

INITIAL CONFIGURATION

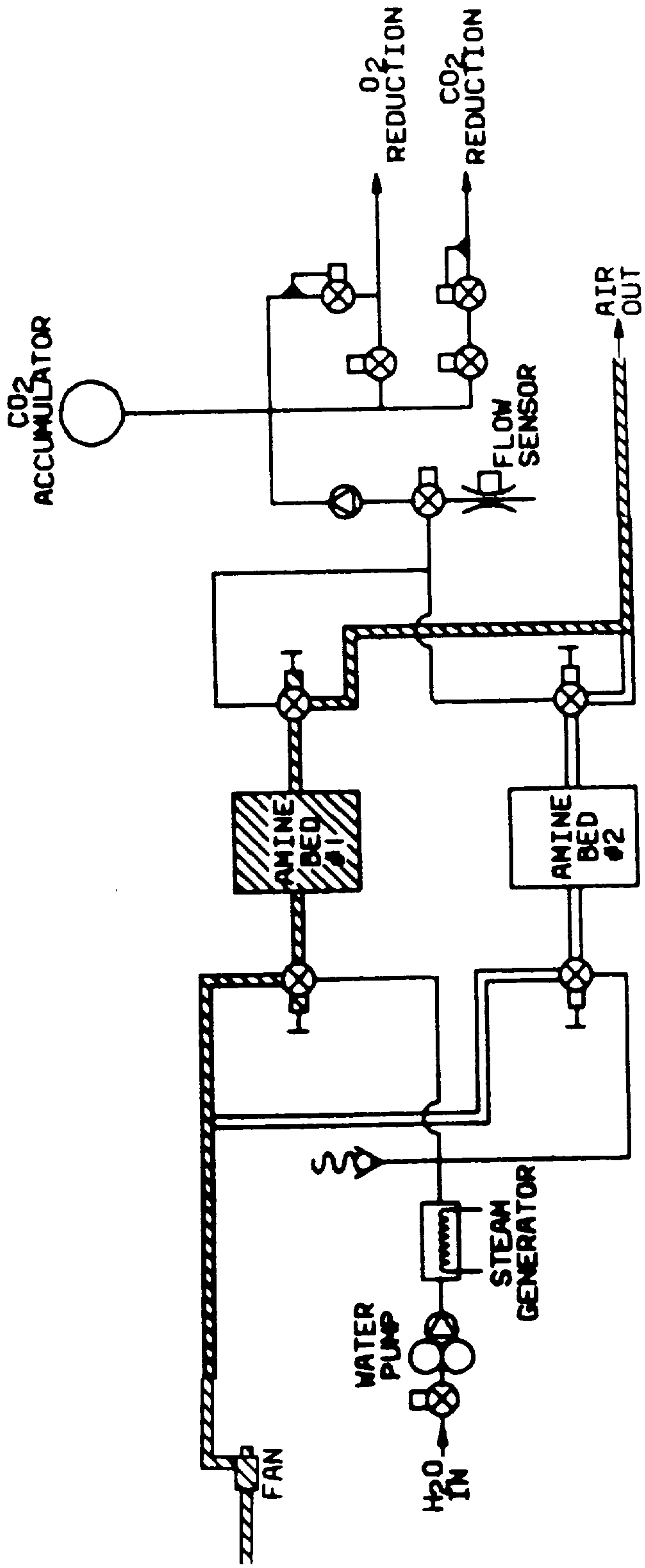

FIGURE 4.3-4

ABSORPTION BED #1 SCHEMATIC

FINAL CONFIGURATION

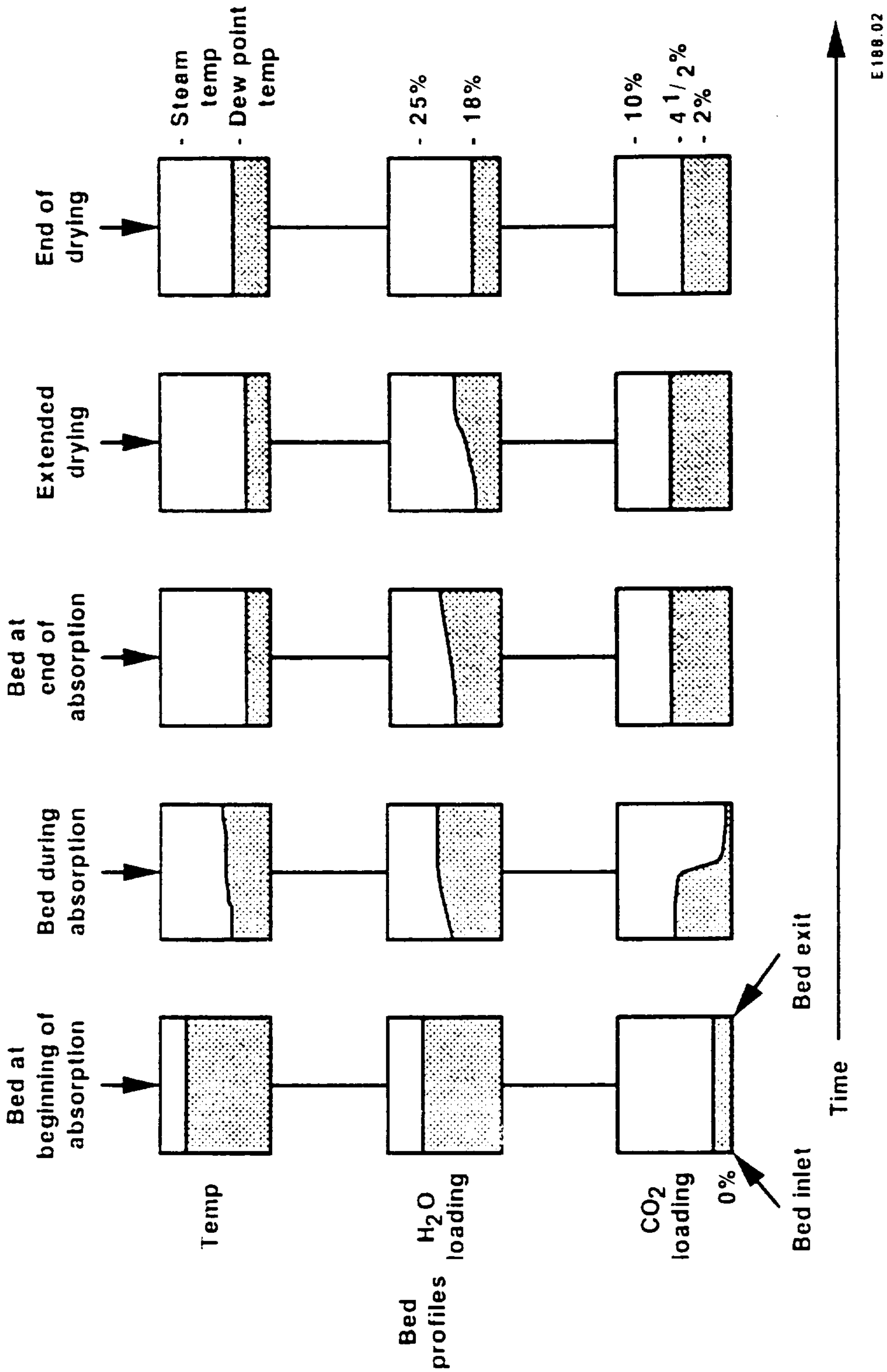

FIGURE 4.3-5
BED CONDITIONS DURING ABSORPTION

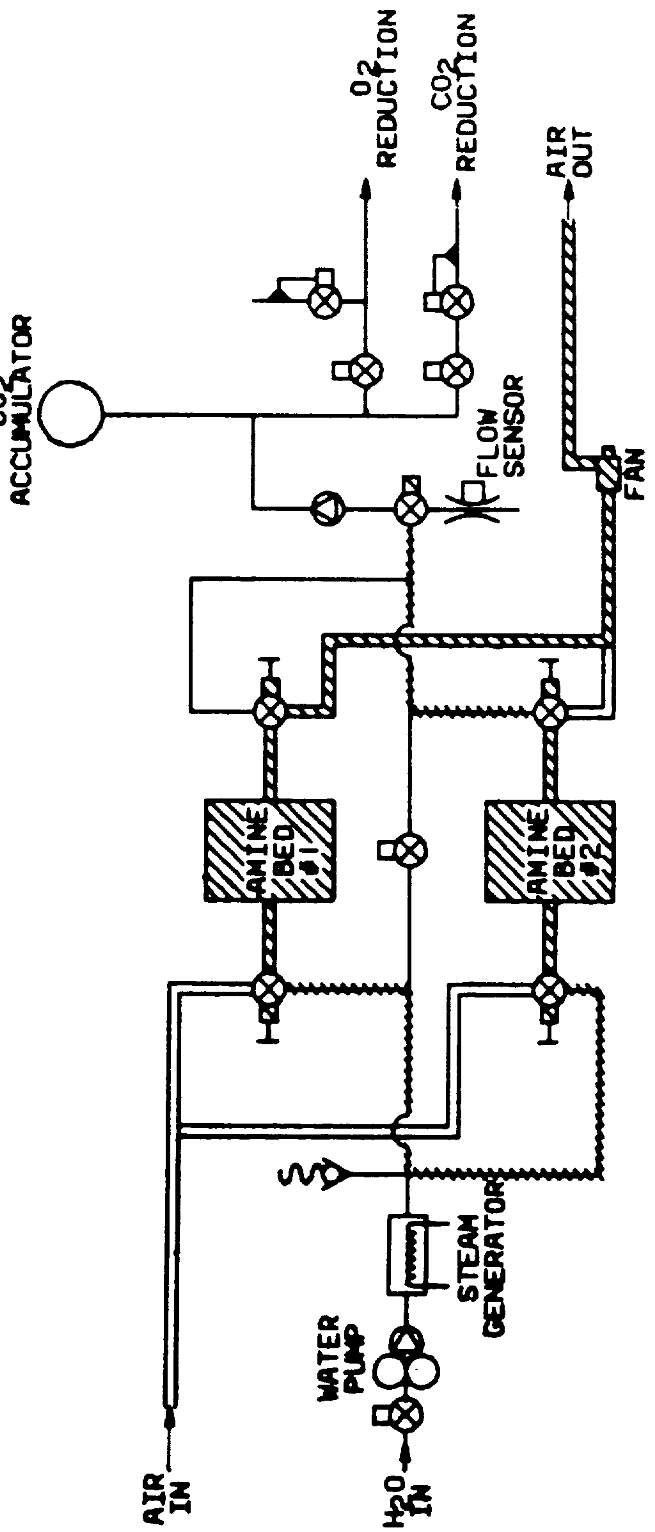

FIGURE 4.3-6

BLEED STAGE (BED #2 TO BED #1)

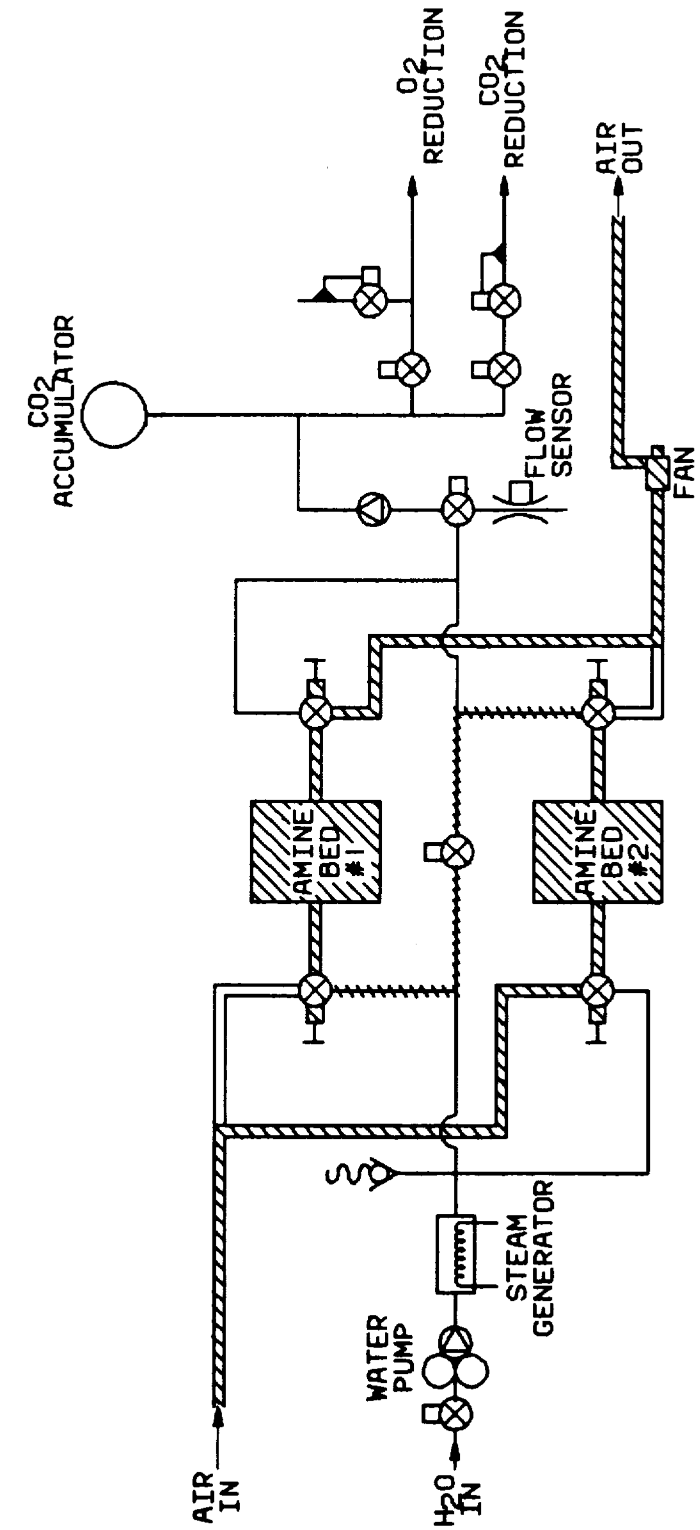

FIGURE 4.3-7

INITIAL CONFIGURATION

ENERGY TRANSFER BED #2 TO BED #1

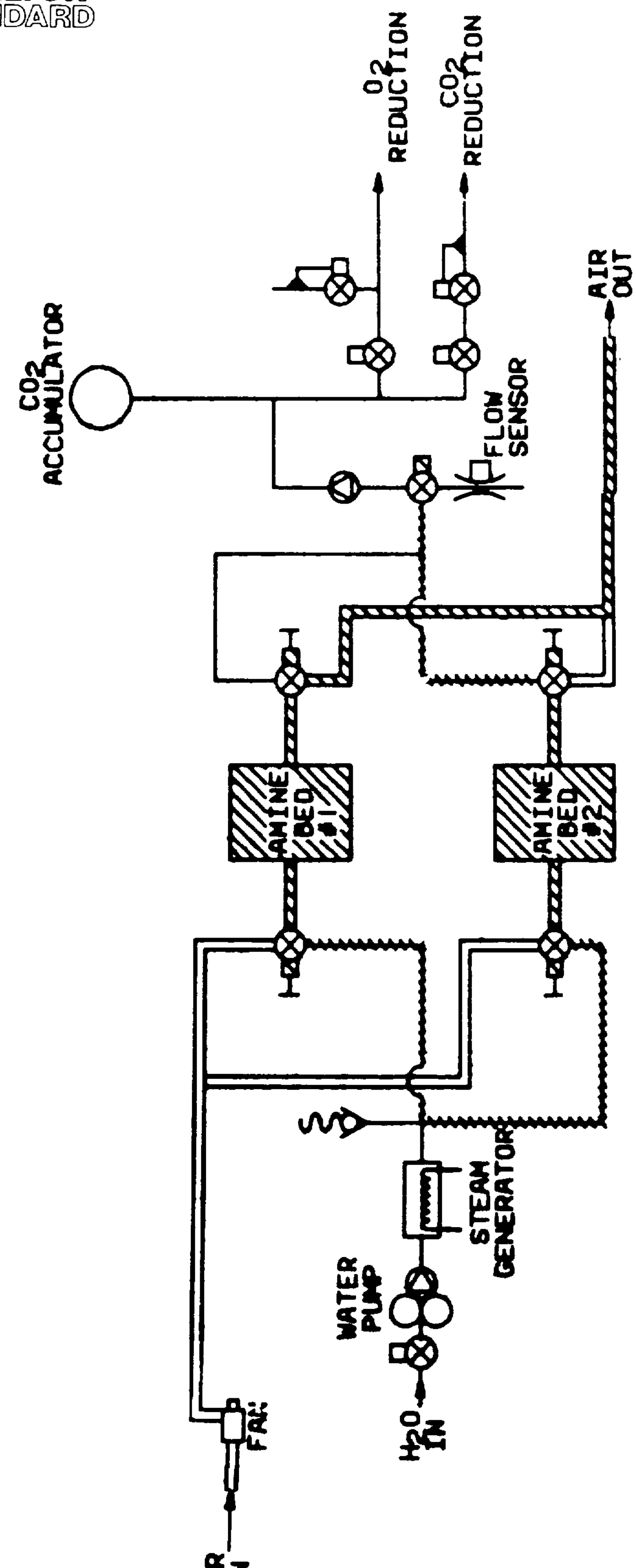

FIGURE 4.3-8

FINAL CONFIGURATION ENERGY TRANSFER

(BED #2 TO BED #1)

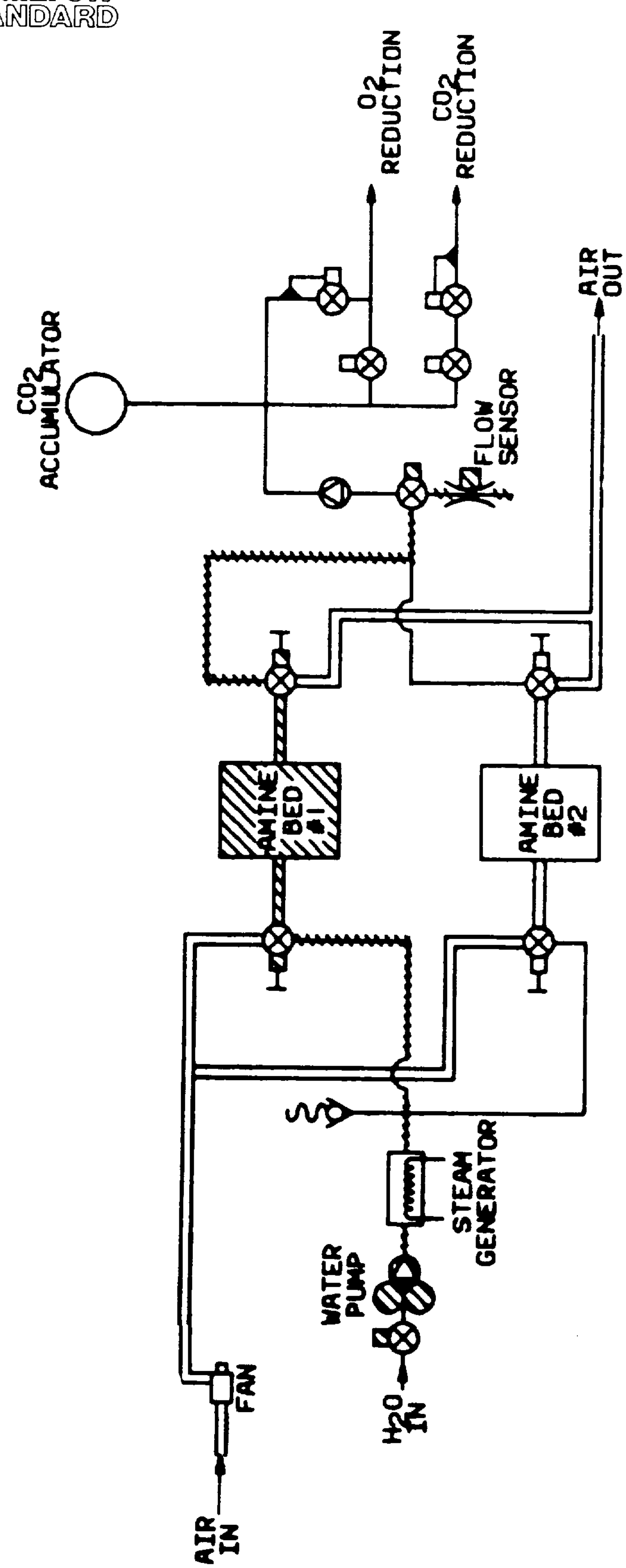

FIGURE 4.3-9
FINAL CONFIGURATION BED #1 VENT STAGE

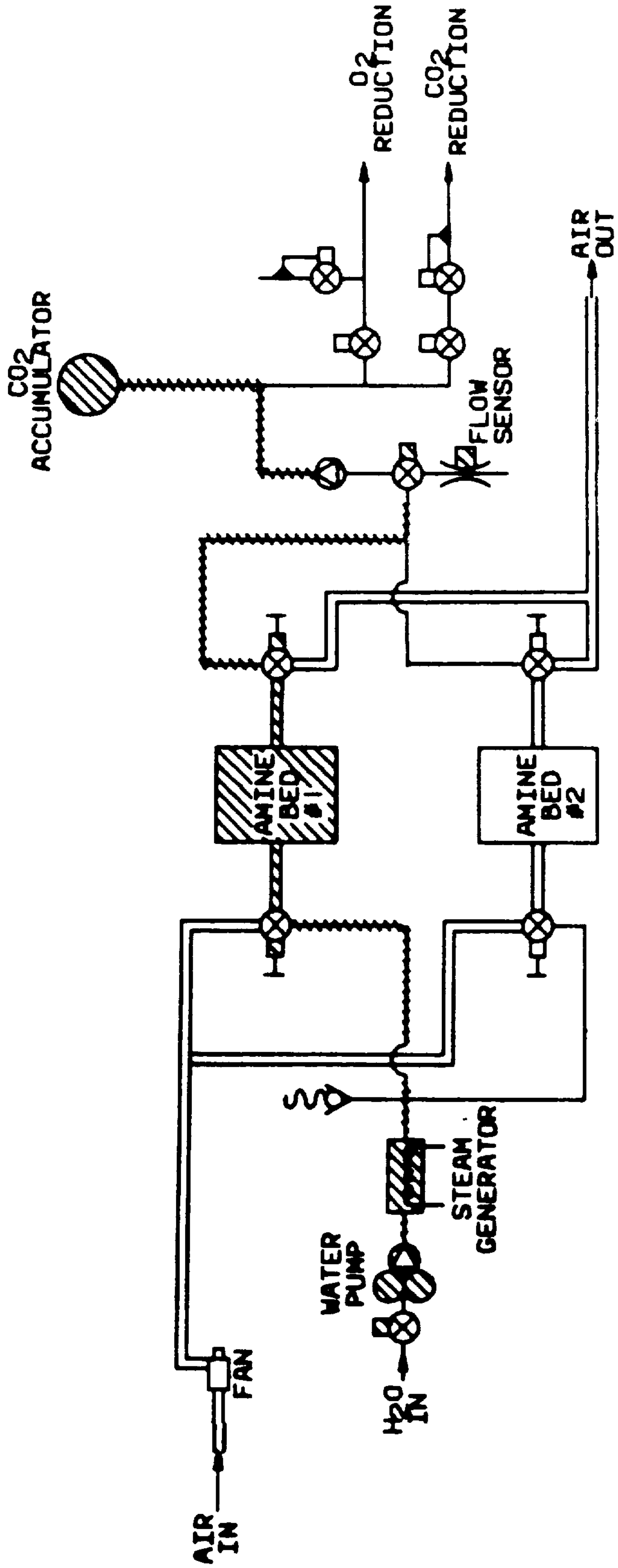

FIGURE 4.3-10

FINAL CONFIGURE BED #1 CO_2 EVOLUTION STAGE

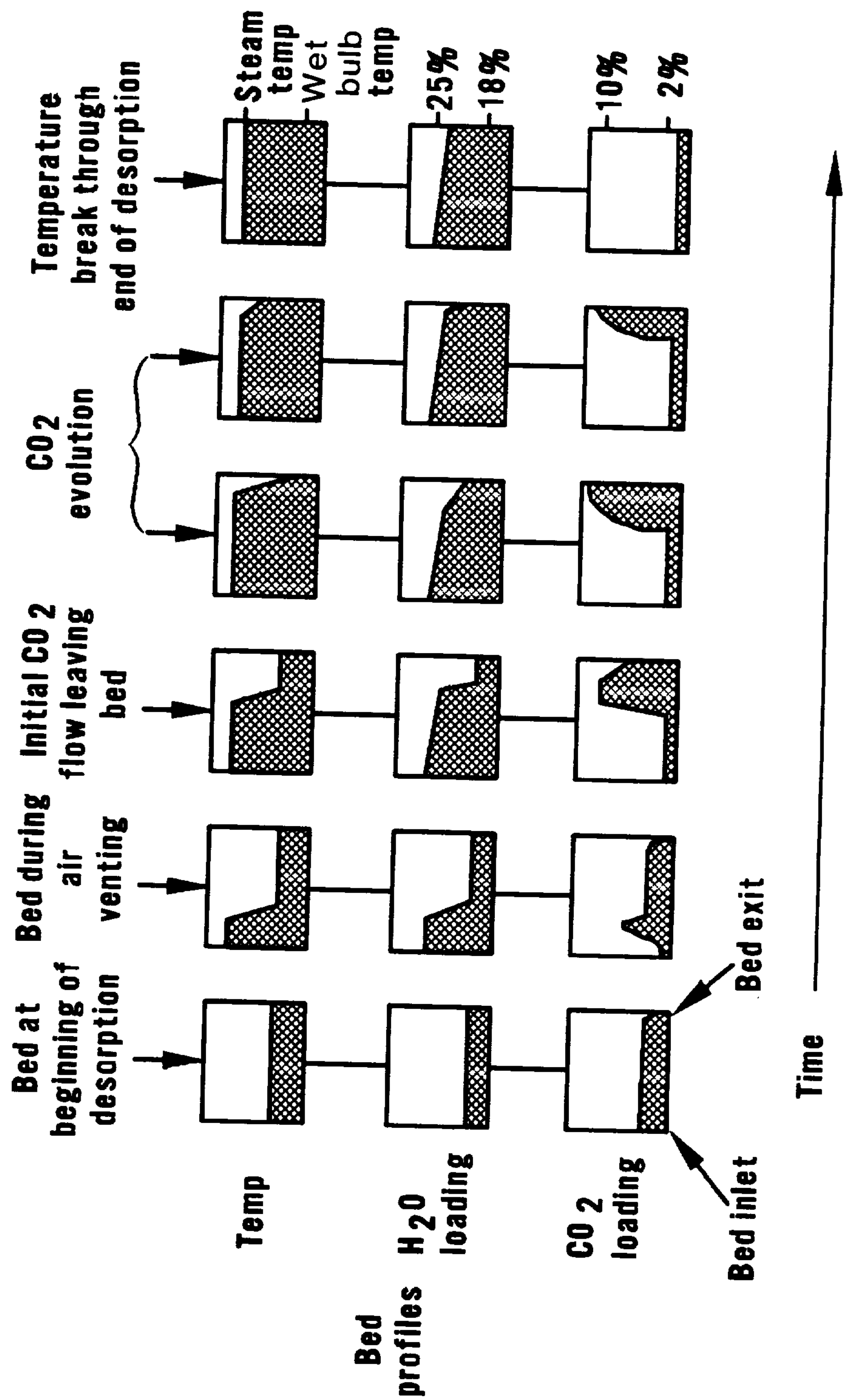

FIGURE 4.3-11
BED CONDITION DURING DESORPTION

TABLE 4.3-1

INTERFACE DESCRIPTIONS

ID#	MEDIUM	CONNECTOR SIZE/TYPE	CONNECTED TO
J401	115 VAC 400 HZ	ELECTRICAL CONNECTOR P/M PT061-10-98S (SR)	DRIVER BOX
J402	115 VAC 60 HZ	ELECTRICAL CONNECTOR P/N PT06A-14-5S (SR)	DRIVER BOX
J403	28 VDC	ELECTRICAL CONNECTOR P/N PT06A-14-12-3S (SR)	DRIVER BOX
J108	RS232	ELECTRICAL CONNECTOR P/N DB19678-2	NOT USED*
J106	1553 B DATABUS	BUS COUPLER - DBC 34302A TWIN ARIAL CABLE - TWAC-78-1F1 CONNECTOR-PL75-47	DCC
J107	1553 B DATABUS	BUS COUPLER - DBC 34302A TWIN ARIAL CABLE - TWAC-78-1F1 CONNECTOR-PL75-47	DCC
J109	RS232	ELECTRICAL CONNECTOR P/N DB19678-2	NOT USED*
CA1	CO_2 ACC.	1/4" CPV FITTING	ACCUMULATOR
CR1	CO_2 REDUCTION	1/4" CPV FITTING	
CD1	CO_2 OVERBOARD	1/4" CPV FITTING	OVERBOARD
W1	WATER	1/4" CPV FITTING	WATER SUPPLY
A1	AIR IN	2" OD TUBE CLAMP FOR A FLEXIBLE HOSE	CABIN/TEST RIG SOURCE
A2	AIR OUT	2" OD TUBE CLAMP FOR A FLEXIBLE HOSE	CABIN/TEST RIG

*CAN BE CONNECTED TO A TRS-80 FOR ALTERNATE CONTROL SCHEME IF A DCC IS NOT AVAILABLE OR TO A DATA LOGGER FOR DATA ACQUISITION.

4.4 Performance Testing

This section describes the significant test results that were obtained during system testing. A section of related component test results is also provided. The parametric and life test results presented in the component section were obtained on a single Zero-g canister breadboard subsystem. Since the canister and amine are identical to the canisters used on the subsystem, the results are directly applicable and are provided for completeness.

4.4.1 Performance Evaluation Procedure

During the subsystem testing a procedure was developed which resulted in both accurate and repeatable test results. That procedure is summarized in this section.

In addition to the system instrumentation, the following facility or rig instrumentation was utilized.

- 0 to 20 inch water manometer
- 0 to 100 cubic feet wet test meter (0.1 cubic feet per revolution)
- 0 to 1% CO_2 concentration analyzer
- optical/condensation Hygrometer (dewpointer)
- 0 to 1 pph CO_2 flowmeter
- 0 to 300 lbs. scale

In order to facilitate measurements, test ports were added to the system. The "as designed" system was modified by replacing the flexible air line at the blower inlet with a section of "tygon" tubing. This tubing contained a test port to permit the blower inlet pressure to be measured. Additional lengths of line were added to the air inlet and exit lines of both the "as designed" and "as delivered" configurations. These lines contained test ports to permit the addition and measurement of the CO_2 concentration humidity level and system pressure drop. The "as delivered" system was modified by replacing the flexible air line at the blower exit with a section of "tygon" tubing. This tubing contained a test port to permit the blower outlet pressure, the CO_2 concentration and the inlet relative humidity to be measured. In addition, a tank and sight gage were used to keep track of the amount of water required to desorb the beds. During part of the testing the tank was also placed on the scale and the actual change in weight measured.

The relative humidity of the air was controlled in two ways. Initially it was maintained by a facility saturator/condenser combination. Later, when this rig was not available, the air inlet was humidified by a 1.5 gallon sonic room air humidifier.

In order to establish a repeatable basis for comparison, the beds were conditioned to the same water loading prior to beginning a test series. This was accomplished by placing both beds in the absorb configuration and operating the process air blower (in the manual mode) for 12 or more hours. Based on previous R&D testing this results in a water loading of approximately 12% for 50% relative humidity.

After conditioning the beds a normal start was made and the desired test series conducted.

During the test series, data collection was made as follows.

The cycle during which the test measurements are made, is referred to as the target cycle. During the half cycle prior to the target cycle, the H_2O and CO_2 analyzers were connected to the air inlet and the water manometer was connected to measure the fan head rise. Approximately five minutes prior to the target cycle, the wet test meter was connected to the "overboard" vent interface fitting. Then using either the "DCC" or "TRS-80", overboard operation was selected. The final preparation involved disconnecting one of the leads from the ullage air/accumulator valve (item 406). This resulted in all the ullage air and desorbed CO_2 being passed thru the wet test meter.

At the beginning of the target cycle, the bed being desorbed, the total weight of the water tank, and the wet test meter reading were recorded.

After approximately 15 minutes during the first half-cycle of the target cycle, the process air blower speed and head rise and the CO_2 inlet concentration in the air were recorded. Using the CO_2 flow and concentration, the actual air flowrate could be calculated. Blower performance could be evaluated from speed, flow, and head rise.

After measuring the CO_2 inlet concentration, the CO_2 analyzer was reconnected to measure the outlet CO_2 concentration. (Note the outlet concentration would not be measured during the first few minutes because the high humidity level in the outlet air could damage the analyzer.)

The outlet CO_2 concentration was recorded every several minutes until the outlet concentration reached the inlet level or the half-cycle was nearly complete. Based on the shape of the resulting CO_2 concentration versus time (referred to as the break-through curve), a qualitative determination of the bed water loading can be made for the IR45 amine as indicated on Figure 4.4-1. This is less true for the WA21 amine as indicated on Figure 4.4-2. (Note a good break through characteristic is a very steep rise that occurs late in the cycle, a slow gradual rise, starting early in the cycle indicates too much water and a steep early rise indicates too little water).

At the end of the half-cycle, the water tank weight and the wet test meter reading were recorded. The total water used, and an estimate of the steam generator power could be made from the tank measurement. The CO_2 removal rate could be made by subtracting 0.45 cubic feet from the observed change in the wet test meter. This is equivalent to the ullage air volume.

The process was repeated for the other bed during the next half-cycle.

4.4.2 System Results

During the first test period (0 to 1300 hours), the major objective was hardware and software debugging. During this period the item 308 CO_2 mass flow transducer (hot wire anemometer) failed to operate properly due to moisture in the desorbed CO_2. It was replaced by a orifice (valve) and delta pressure transducer. This combination was more tolerant to moisture in the CO_2 and operated satisfactorily throughout the remainder of the testing.

As previously stated, no CO_2 removal or efficiency measurements were made during the first phase of testing. However, two things became apparent. First, the moisture content of the amine beds was not responding as expected. Secondly, the CO_2 removal rate was lower than expected.

At the beginning of the second phase of testing a baseline CO_2 capacity test was conducted. Prior to the test the amine beds were conditioned by operating the process air blower for 16 hours at the maximum blower speed. During this period the room air humidity varied between 45 and 50%. Based on previous testing this results in a bed water loading of between 10 and 12%.

The test plan called for running a fixed absorb time of 90 minutes at an air inlet condition of 72 +/- 2^{o}F dry bulb, 62 +/- 2^{o}F dew point (approximately 70% R.H.) and a CO_2 inlet partial pressure of 3.0 +/- .1 mmHg. During the testing the process air blower speed was 4550 +/- 50 RPM. This resulted in an air flow of approximately 15 CFM initially, which slowly dropped during the test to approximately 13 cfm.

Based on previous SAWD I and component test experience these test conditions should result in an increase in the water loading over the next 10 to 20 cycles to a repetitive level of approximately 28% when measured at the end of the desorb cycle. The CO_2 removal rate during this period was expected to increase until the water loading became stable and then level off.

A total of 96.5 hours, 53 half-cycles and 4 start/stop cycles were accumulated during this test. The three shutdowns that occurred were caused by power interruptions. They occurred during half-cycles 5, 12 and 27. During half-cycle 13 the rig humidifier ran out of water, this resulted in a dew point of between 34 and 40^{o}F between cycles 13 and 23.

Figure 4.4-3 presents the CO_2 removal rate versus accumulated half-cycle number. The low initial performance was due to the low initial water loading. As the beds increased moisture content, the performance increased until half-cycle 13. The performance then dropped due to the low dew point temperature (beds become overly dry). After the saturator was refilled, the CO_2 removal rate again increased until half-cycle 40. Following cycle 40 bed 1 performance began to drop, while bed 2 became stable at a lower than expected level. (Note Bed 1 is on the left in pictures 1.0-3 and 1.0-7.)

The decrease in Bed 1 performance was the result of the bed becoming overly wet. This is evident by the change in its break-through curve (Figure 4.4-4). Although Bed 2 did not appear to become overly wet in Figure 4.4-3, a review of its break-through characteristic (Figure 4.4-5), indicates a decrease in absorption capacity between cycles 51 and 66. In addition, it took more steam to heat the bed with each successive cycle. This is an indication that the bed was increasing moisture content (i.e. more thermal mass).

Considerable testing was done in the following month to identify the problem and how to solve it. Based on these tests the following scenario was developed.

During absorption, the bed air inlet three way valve (bottom of canister), is cooled by the air flowing thru it. This causes some steam, which is in contact with the back side of the valve, to condense in the line. The exact amount of condensate was never measured, however, based on heat transfer calculations, it is believed to be between 0.15 to 0.905 pounds per hour (50 to 150 BTU's per hour). During the next desorb cycle, when the valve is closed to the air and opened to the steam, the condensate flows into the valve housing due to gravity and the force of the steam flow.

When the valve is repositioned at the beginning of the next absorb cycle, the condensate flows out of the valve and back along the air inlet line where it collects in a puddle. As the air passes over the puddle, some of the water is evaporated. This results in a much higher relative humidity at the bed inlet and reduces the air's ability to properly dry the beds. Assuming that the air saturates along a constant wet bulb temperature line, it only takes approximately 0.1 pounds per hour of condensate to increase the relative humidity of 15 CFM from 70 to 100% at 72°F. During the testing the air inlet line was removed several times and the amount of condensate measured. The amount of water collected was approximately 0.25 pound and appeared to be independent of the number of cycles that had been run. This indicates that an equilibrium puddle size is established.

The reason that Bed 1 tended to be wetter than Bed 2 is because the air that flows into Bed 1 must first pass over both the condensate from Bed 2 and Bed 1. Bed 2's air only had to pass over the condensate from Bed 2. The plumbing was modified (see figures 1.0-3 and 1.0-7), so that any condensate from Bed 2 is contained in the tube between the main air line and Bed 2.

In order to evaporate this condensate the fan was relocated from the subsystem outlet to the inlet. This permits the 15 to 30°F temperature rise across the fan to be utilized to dry up the condensate. Figure 4.4-6 presents the results of testing utilizing this configuration. The test was similar to the initial baseline test, except that it was possible to reduce the absorption time to 45 minutes and still maintain a stable water loading.

With the water loading problem under control, we next turned our attention to the lower than expected CO_2 removal rate.

The first step was to replace the IR45 with new WA21 amine. When the amine was removed from the canister, it was observed that it had significantly changed colors (yellowed). Further analysis indicated that the amine had been oxidized. A series of component tests were conducted which revealed that the rate of oxidation is extremely dependent on temperature. Figure 4.4-7 shows the loss of CO_2 capacity versus hot air (approximately 150°F) exposure time. (Note: exposure to high temperatures during desorption does not seem to cause serious degradation, since no oxygen is present.)

Based on these tests and on the operating procedure, the following scenario was developed to explain the low performance.

The "as designed" system used a small flow of air (approximately 2 SCFM) to transfer some of the energy from the previously desorbed bed to the bed about to be desorbed. This resulted in the hot bed being exposed to oxygen during energy transfer.

To reduce the rate of oxidation, the method of energy transfer was modified (section 4.3.2.4), and the energy transfer valve was eliminated. The unit was also refilled with new WA21.

Figure 4.4-8 presents the system pressure drop versus air flow rate and Figures 4.4-9 and 4.4-10 present blower performance.

After refurbishment there was insufficient time to conduct a full performance map. However, the three man CO_2 removal rate was verified in a short 125-hour final verification test prior to shipping the unit. Because a full performance map was not done, some test results from the "zero-g" SAWD Life Test Stand single canister have been included in Figures 4.4-11 thru 4.4-13. Since the amine and canister are the exact same design it is felt that these results should be typical for the SAWD II system.

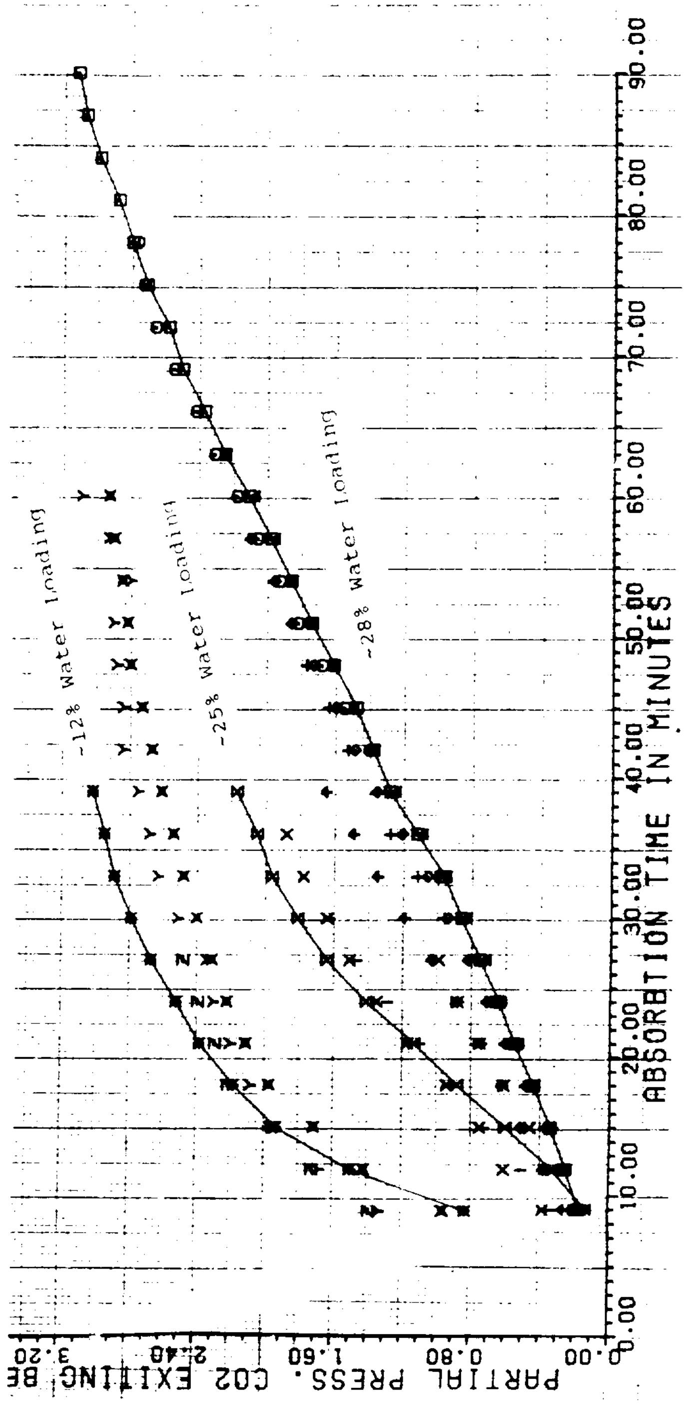

FIGURE 4.4-1

EFFECT OF WATER LOADING ON CO_2 PERFORMANCE (IR45 AMINE)

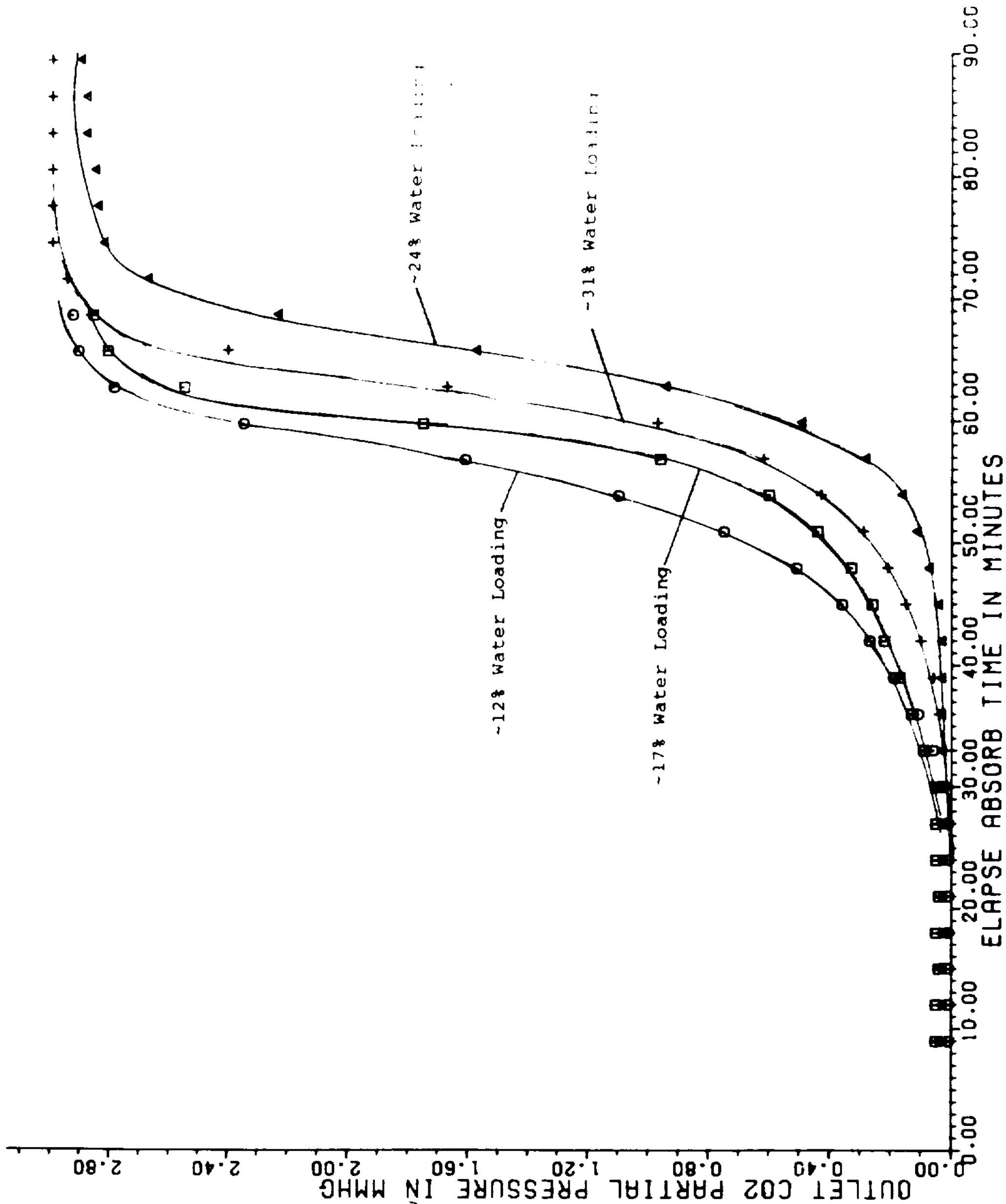

FIGURE 4.4-2

EFFECT OF WATER LOADING ON CO_2 PERFORMANCE (WA21 AMINE)

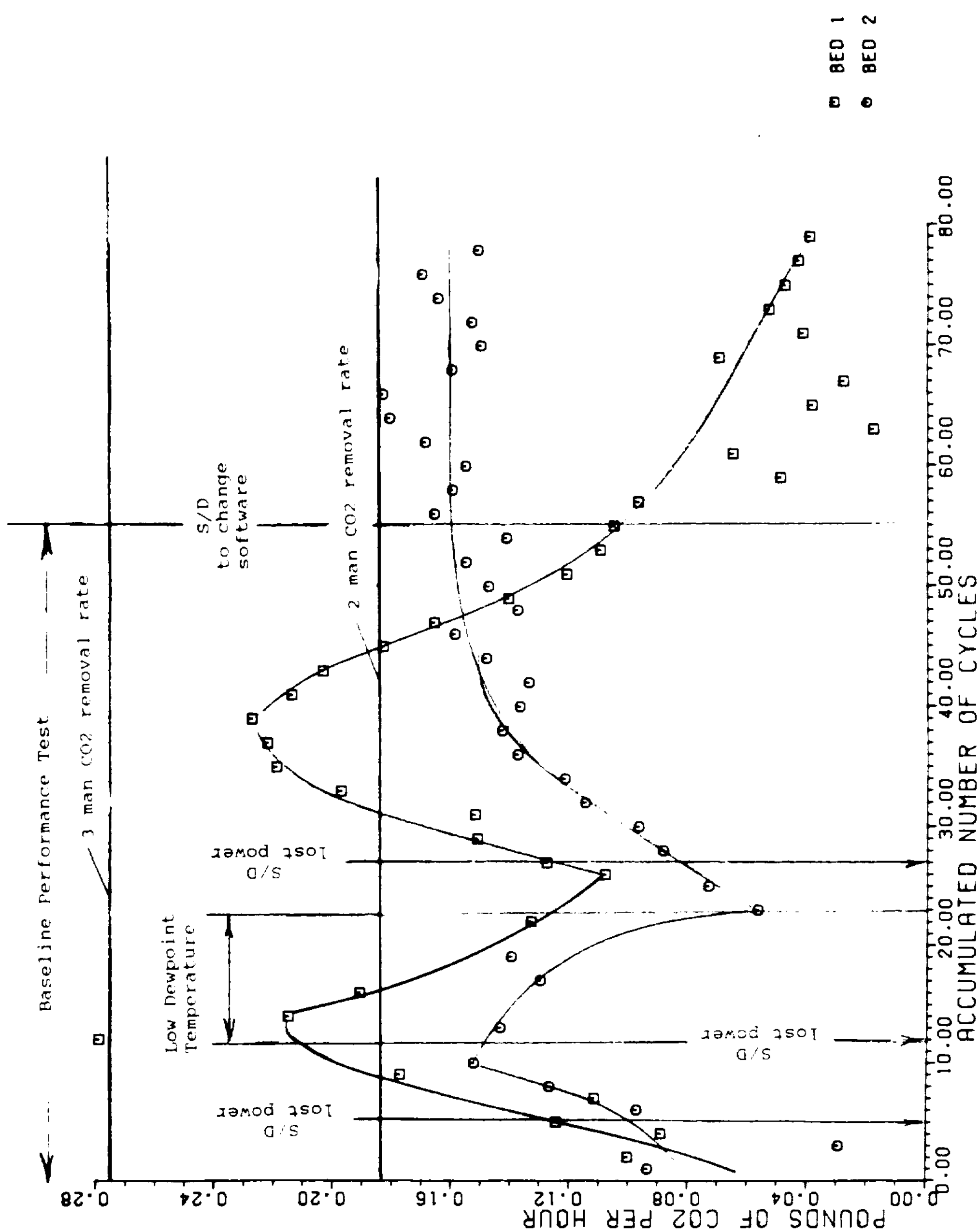

FIGURE 4.4-3

SAWD SUBSYSTEM BASELINE PERFORMANCE TEST

70% RELATIVE HUMIDITY & 90 MINUTES ABSORB TIME

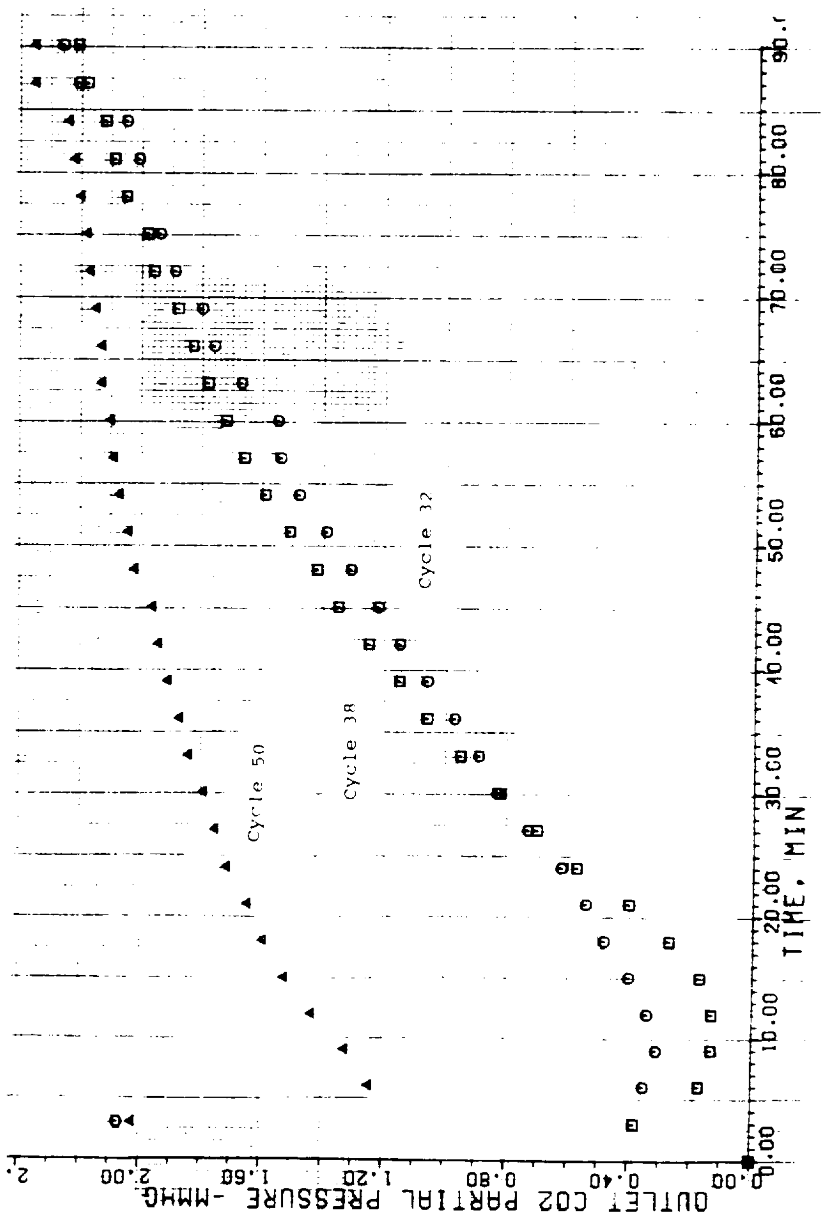

FIGURE 4.4-4

SAWD SUBSYSTEM BASELINE PERFORMANCE TEST RESULT

BED 1 PERFORMANCE (70% RH & 90 MINUTE ABSORB TIME)

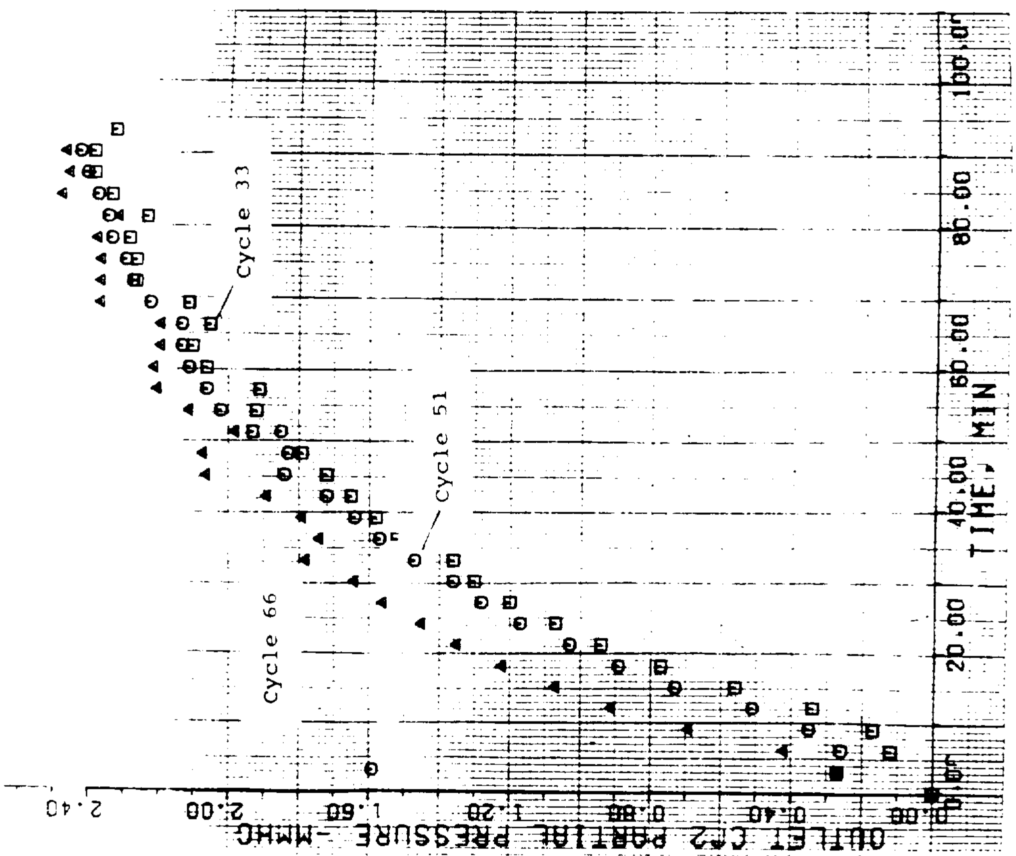

FIGURE 4.4-5

SAWD SUBSYSTEM BASELINE PERFORMANCE TEST RESULT

BED 2 PERFORMANCE (70% RH & 90 MINUTE ABSORB TIME)

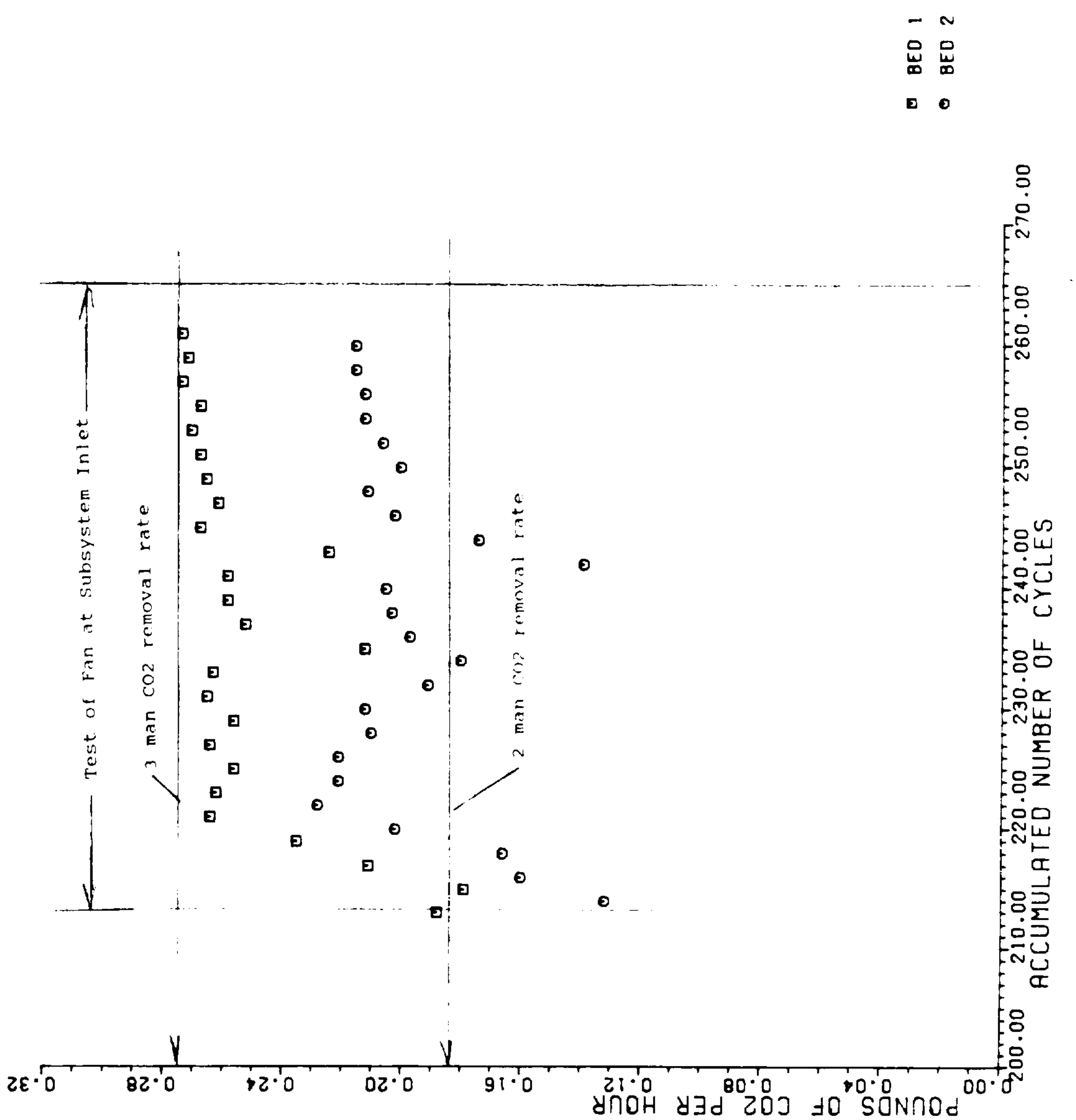

FIGURE 4.4-6

SAWD SUBSYSTEM RECONFIGURED BLOWER TEST

70% RELATIVE HUMIDITY & 45 MINUTES ABSORB TIME

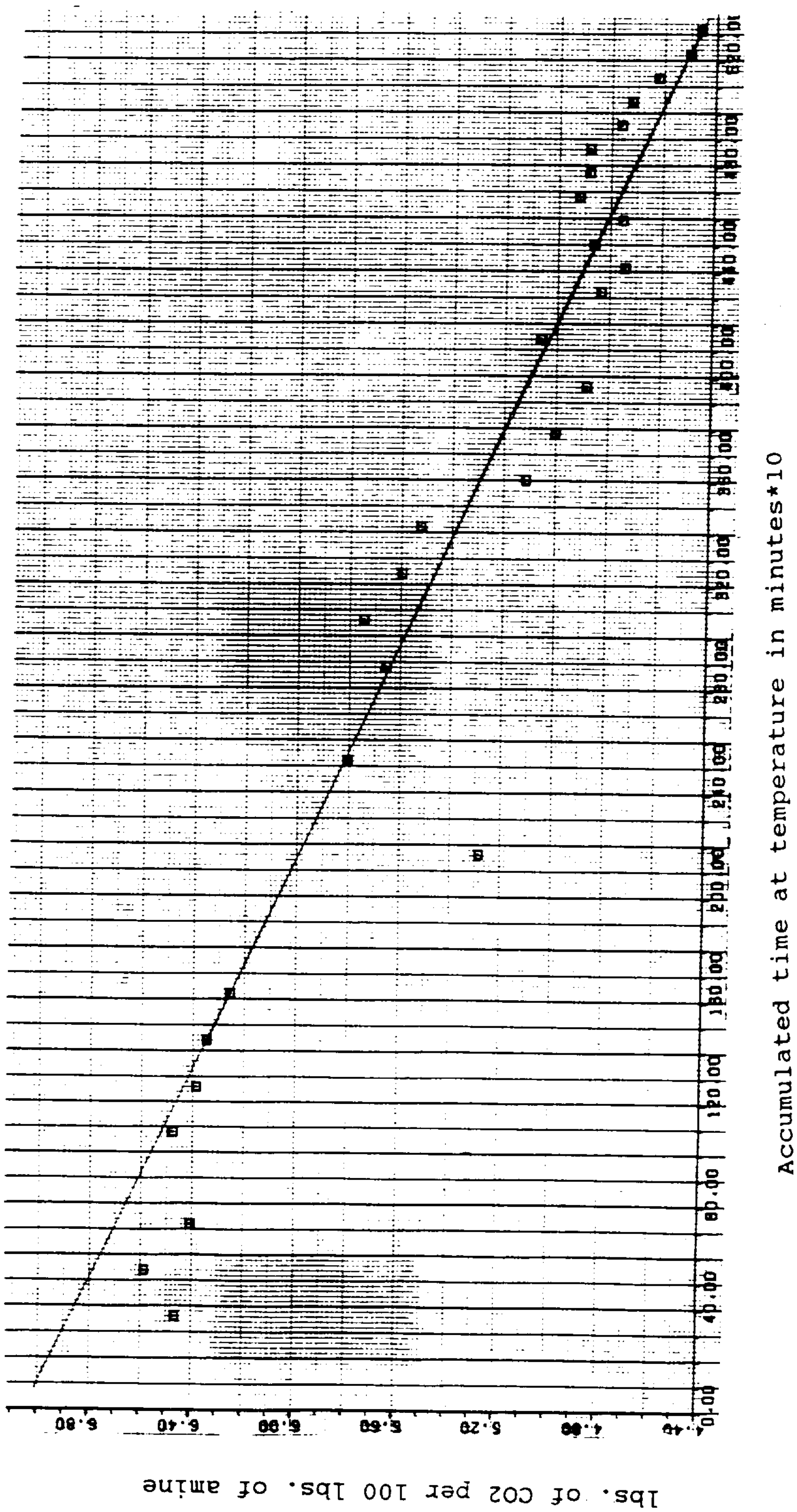

FIGURE 4.4-7

EFFECT OF TEMPERATURE & OXIDATION ON CO_2 CAPACITY

WA21 SINGLE CANISTER COMPONENT TEST RESULTS

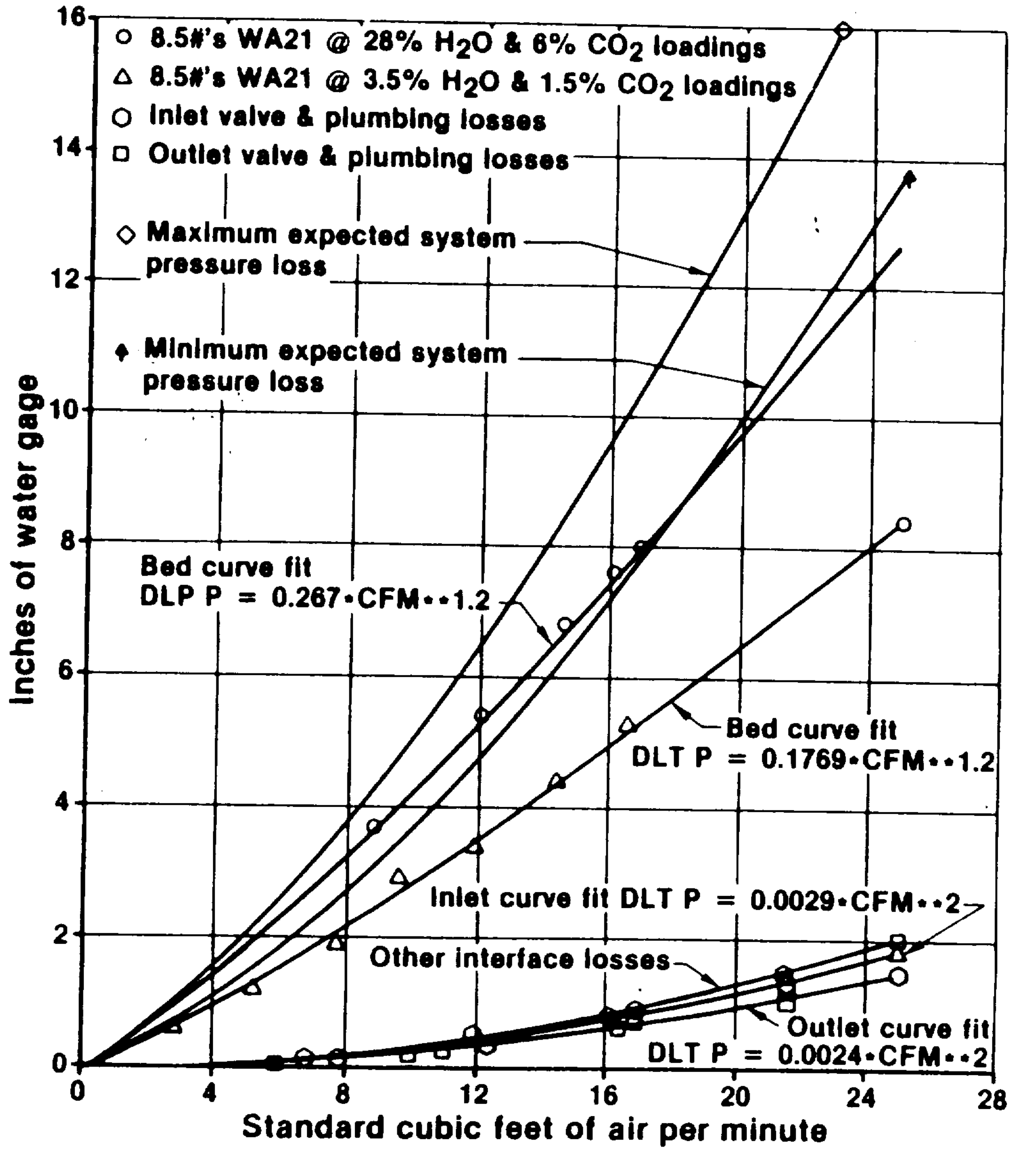

FIGURE 4.4-8

SAWD SUBSYSTEM PRESSURE DROP vs. AIR FLOWRATE

PRESSURE DROP AFTER REFILLING WITH WA21

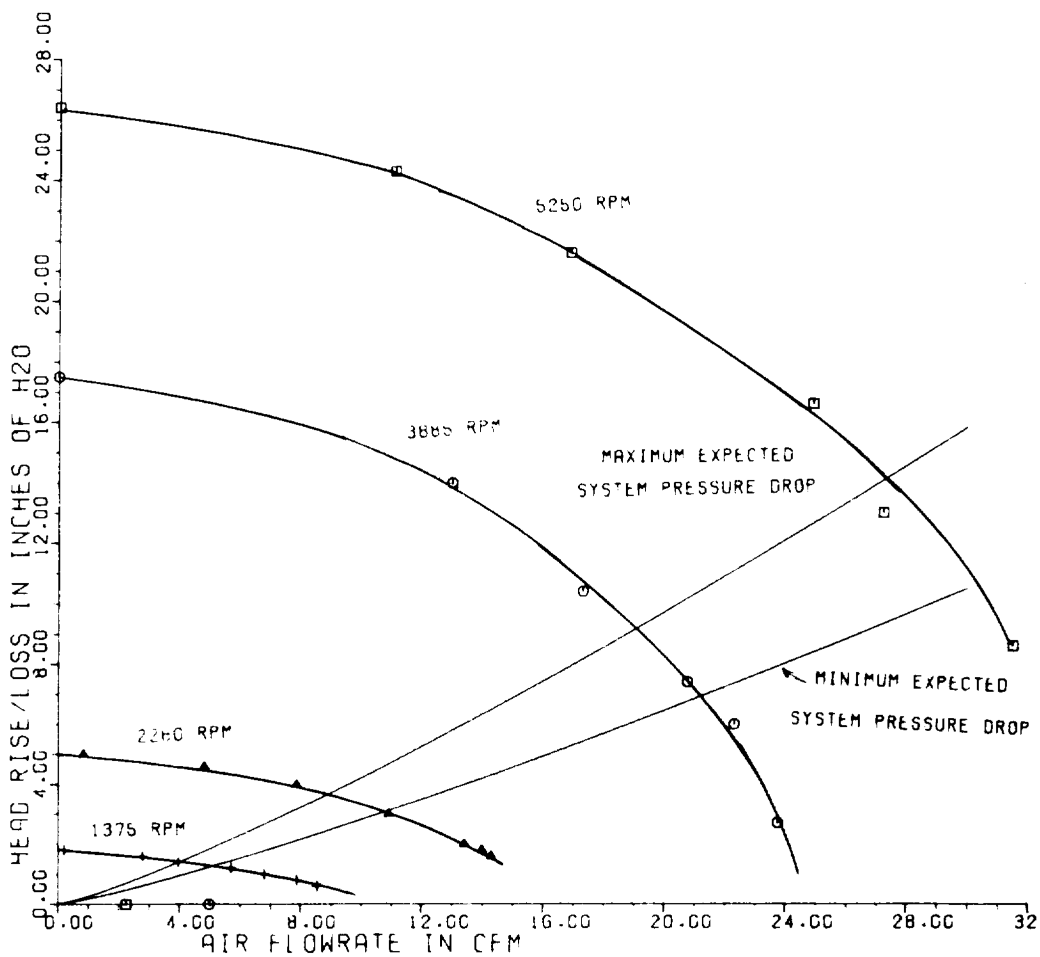

FIGURE 4.4-9
SAWD SUBSYSTEM BLOWER PERFORMANCE
PRESSURE DROP AFTER REFILLING WITH WA21

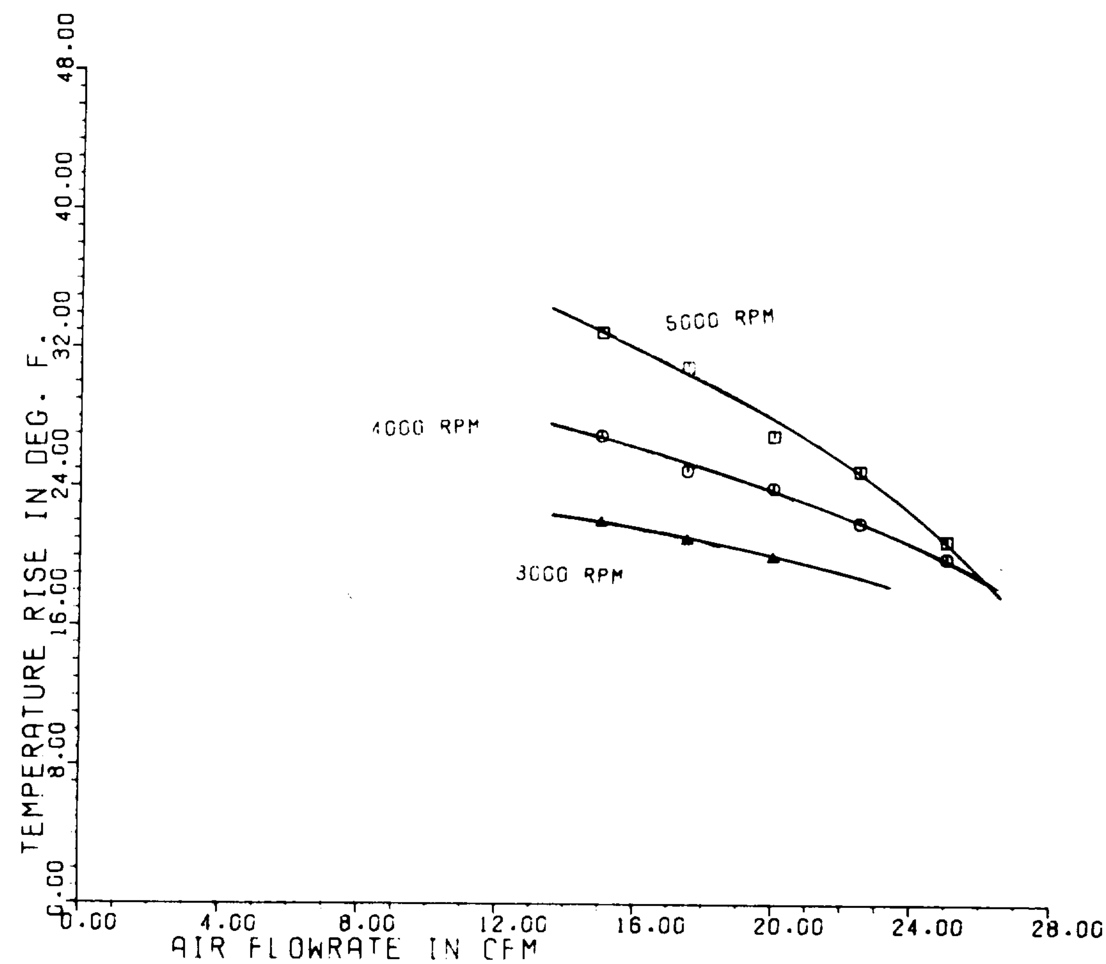

FIGURE 4.4-10

SAWD SUBSYSTEM BLOWER PERFORMANCE

TEMPERATURE RISE vs AIR FLOW RATE

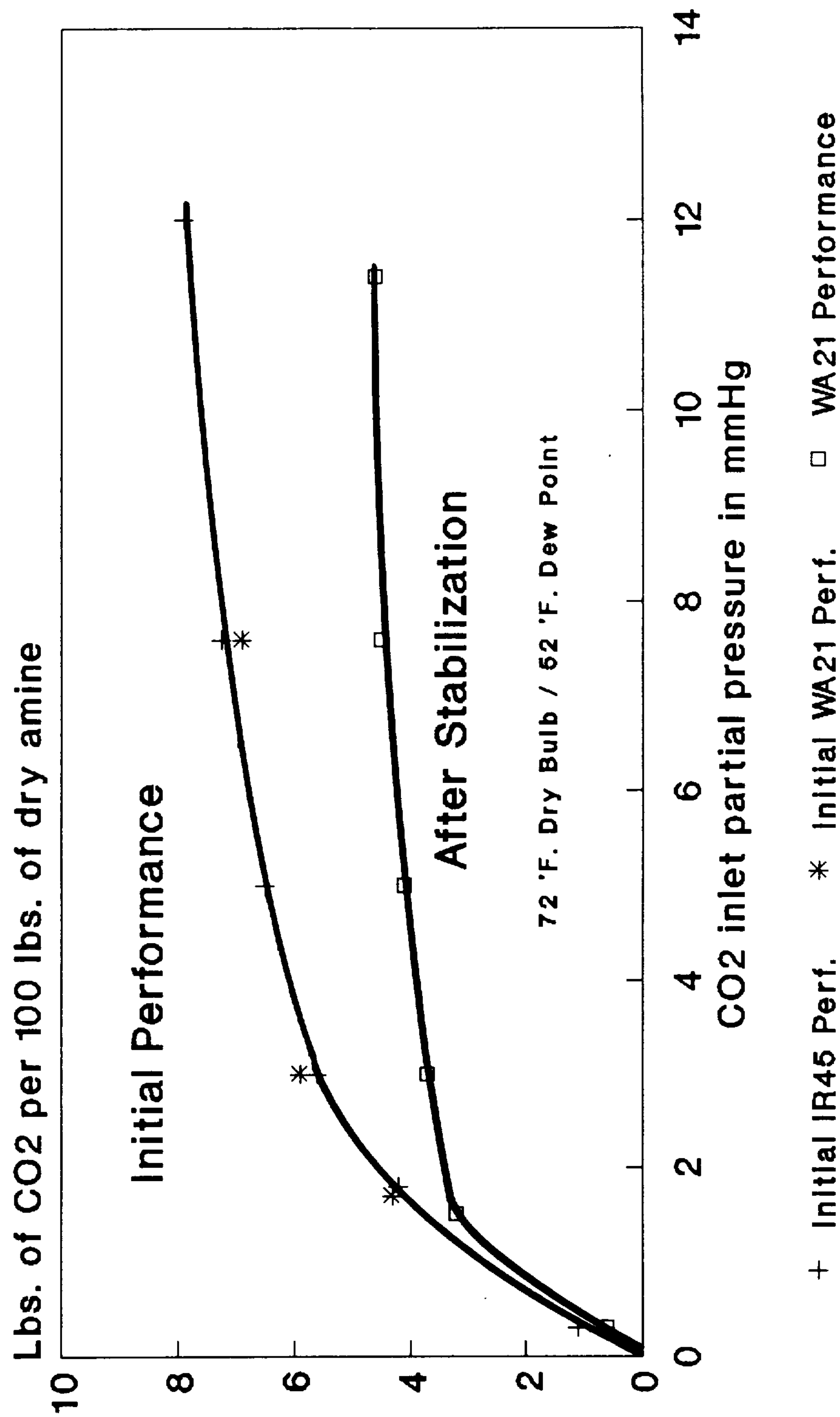

FIGURE 4.4-11
EFFECT OF INLET CO_2 PARTIAL PRESSURE ON CO_2 CAPACITY
RESULTS FROM SINGLE ZERO-G CANISTER TEST

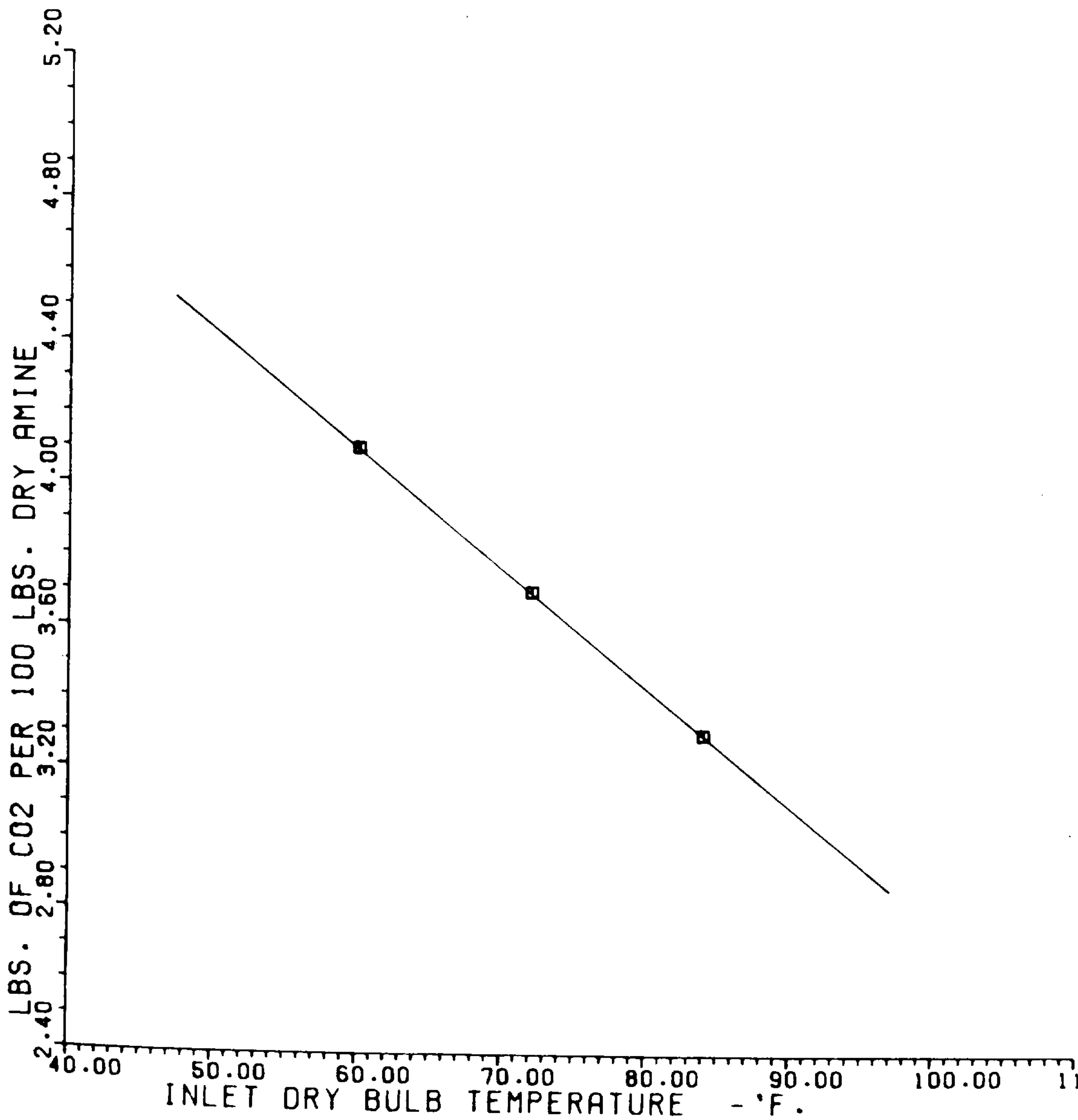

FIGURE 4.4-12

EFFECT OF ABSORPTION TEMPERATURE ON CO_2 CAPACITY

RESULTS FROM SINGLE ZERO-G CANISTER TEST

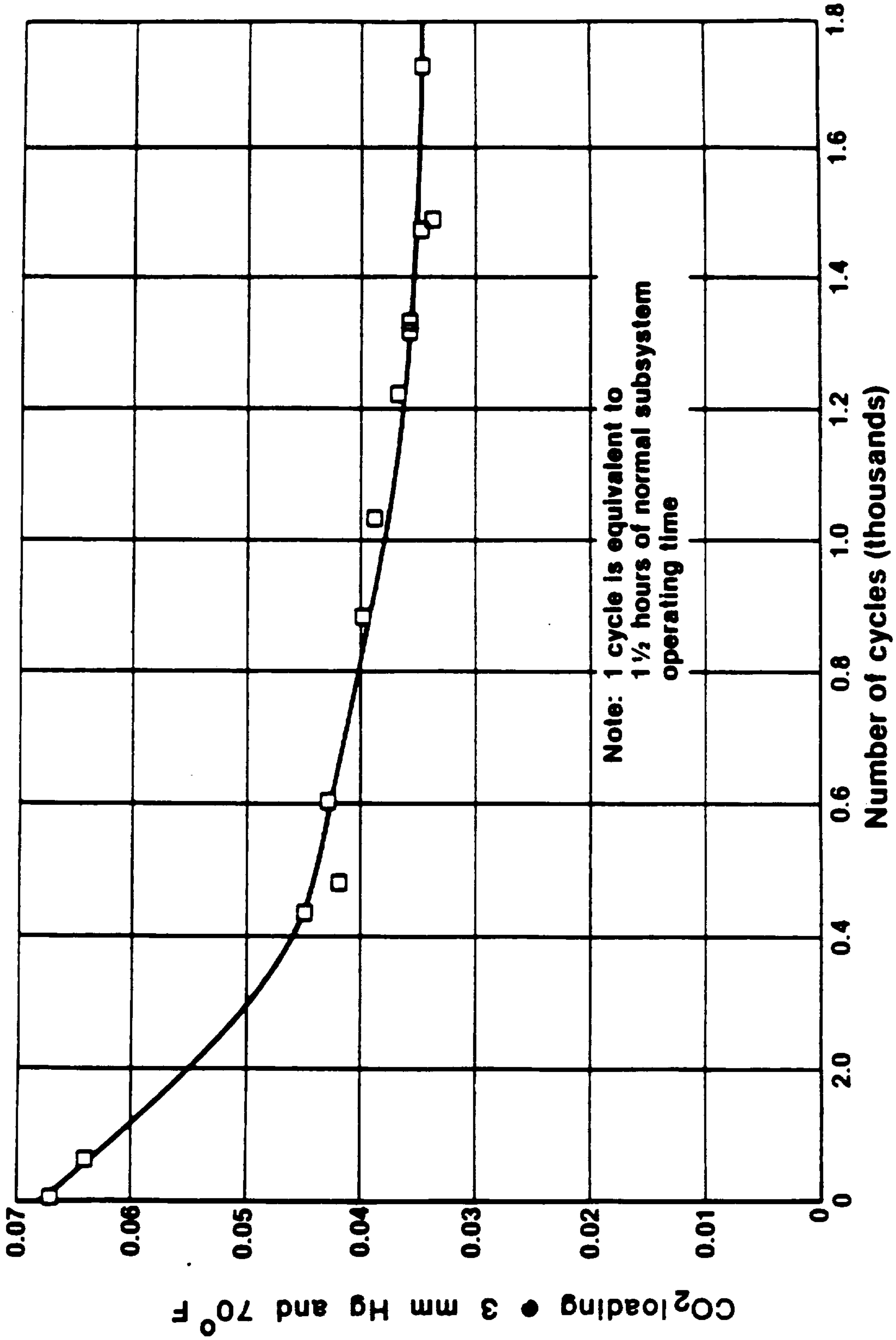

FIGURE 4.4-13

EFFECT OF OPERATING TIME ON CO_2 CAPACITY

RESULTS OF SINGLE ZERO-G CANISTER TEST